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Supplement to the Treatise

WOLFGANG RUNGE: TECHNOLOGY ENTREPRENEURSHIP

How to access the treatise is given at the end of this document.

Reference to this treatise will be made in the following form:
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The current case relates to a group of German university spin-outs or research-based startups (RBSUs), respectively, based on scientific optical instruments and specifically nanotools, WITec GmbH, JPK Instruments AG, and Attocube Systems AG, for which individual case documents are generated. All university startups are more or less competitors, but exhibit different paths of development which represents a "science2business" approach.

This cluster of startups deals with an enabling technology for nanotechnology, very highly resolved microscopy, which was honored with the Nobel Prize in Chemistry 2014 awarded jointly to William E. Moerner, Eric Betzig, both from the US and Stefan W. Hell (Germany) "*for the development of super-resolved fluorescence microscopy*."

In this context the WITec case provides information on technology and markets as well as competitive situations for all the other two startups.

Wolfgang Runge

Attocube Systems AG

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Attocube Systems AG (written attocube systems AG after a change in the shareholding and finally its acquisition by WITTENSTEIN AG) was founded in 2001 as a spin-out of the CeNS (Center for NanoScience) at the Ludwig-Maximilian-University (LMU; Munich/Germany) focusing on nanotools [Runge 2014a].

Attocube was founded essentially by an entrepreneurial pair [Runge:191,306,328], a very creative scientist (professor of physics) and a complementary PhD (Dr.) physicists with an intrinsic commercial business mindset.

It develops, manufactures and, through a worldwide distribution network, sells spatial *nano-positioning systems* and *complete probing tools* which are particularly suitable for extreme environmental conditions. Ultra-high precision spatial positioning of objects is central to most fields of nanotechnology.

The fundamental innovation of the company was the development of ultra-compact, nano-precise *positioning devices*, which were – for the first time ever – adaptable to *extreme conditions*, such as *cryogenic temperatures* (close to the absolute zero point of temperature, -273.15°C, or 0 K, down to 300 mK), *ultra-high vacuum* environments (5x10-11 mbar) and *highest magnetic fields* (+31 T).

In particular, Attocube develops and produces also a broad range of *scanning probe microscopes* (SPMs) used in basic and industrial research. Attocube's nanopositioners and related accessories and SPMs are used in a variety of industrial applications, such as the semiconductor industry and micromachining, life sciences and telecommunications.

The Technology and the Market

Technologies and markets for atomic force microscopes (AFMs), scanning probe microscopes (SPMs) and scanning near-field microscopes (SNOMs) are described essentially in the WITec case [Runge 2014a] and case of JPK Instruments [Runge 2014b]. This can be subsumed under the heading *nanotools essentially for nanoanalytics*.

"*Nanopositioning* is the art of motion control on a very small scale at a very fast rate." [Coffey 2010] Particularly, nanopositioning is usually understood as positioning control to atomic and molecular levels of the order of nanometer resolution. *Nanopositioning tools* provide repeatable, high-precision motion with increments of 1 nm or less over a range of several microns. Applications include super-resolution microscopy under various conditions, metrology, nanolithography, interferometry and imaging, among others. "The big push right now is bio: cell biology and microscopy using super-high-resolution optical microscopes." [Coffey 2010; Mather 2012]

Researchers who want to make, for instance, the atomic structures of new semiconductor or silicon chips visible on their screens, need also during the investigation the sample material to be pushed through under a scanner as exactly as possible to the nanometer.

Architecturally, a nanopositioner is a mechanical stage that consists of a moveable component inside a rigid frame. A basis of nanopositioning refers to the *slip/slide* (also called *stick/slip*) principle which means movement of two surfaces relative to each other that proceeds by a series of jerks caused by alternate sticking from friction and sliding when the friction is overcome by an applied force (Figure 1).

Almost everyone knows the slip-slide principle from TV shows: If one pulls the tablecloth quickly, sharply and suddenly enough (by a jerk) the tableware or coffee service standing thereon is not endangered; the objects on the table's surface stay in their place. Similarly, the slow motion of a smooth slide of titanium carries a titanium object lying on it to a new position; if then the titanium slide pulls back very quickly the object stays in its (new) place.

Most commonly, nanometer-scale positioning is based on a *piezoelectric ceramic* stack that expands or contracts according to an applied voltage. [1] Piezoelectric stacks limit the distance a positioner can travel, producing so-called "short travel" positioning of the order of hundreds of microns [Coffey 2010].

The main rule of nanopositioning says that there must be no friction pairs in nanopositioning systems. That means that all devices which have roll or slip bearings (in German Gleitlager) cannot be the constituent of a nanopositioning system. But air slip bearings and *flexure guide* may be used in nanopositioning as flexure guide [2] has no friction pairs (no parts which move against each other), their work is based on elastic deformation of productive flexure of solid body.

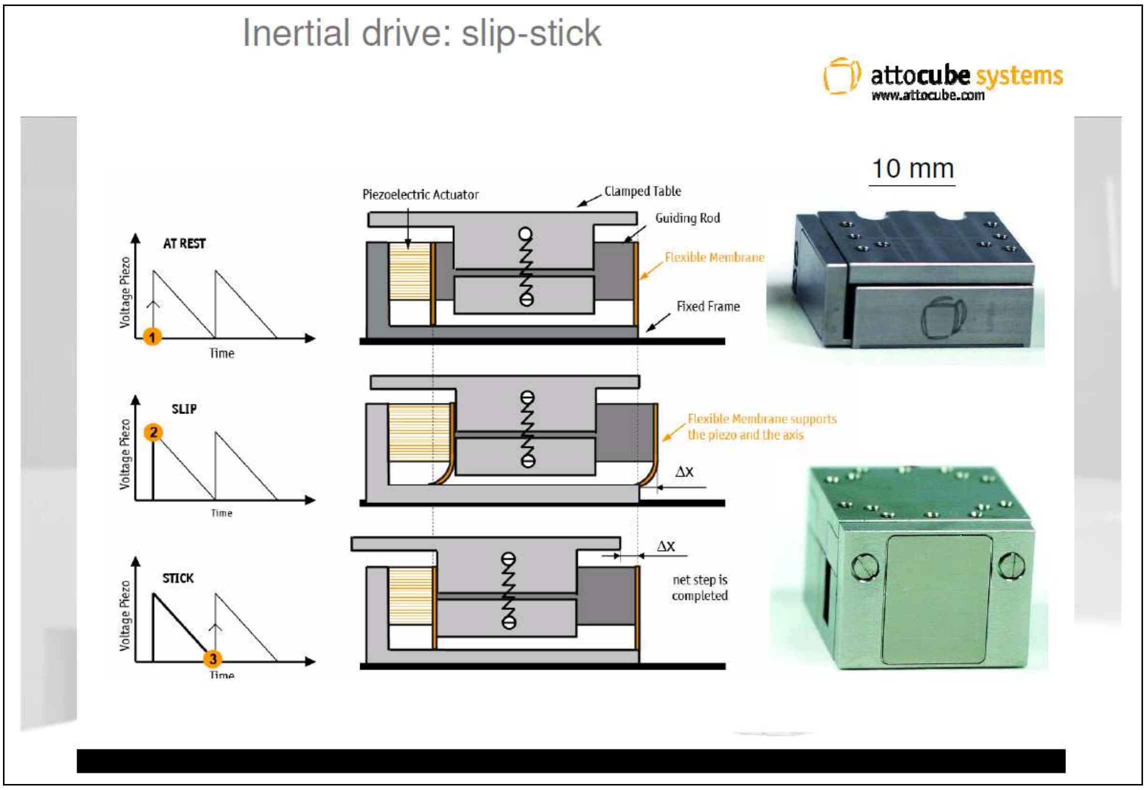

Figure 1: The slip-stick principle illustrated for Attocube's nanopositioners [Karrai 2007].

Nanometer-scale performance requires a frictionless drive, so nanopositioning stages are usually flexure guided or driven by some type of solid-state *actuator* (in German Stellglied). In addition to an actuator and a guiding system, many nanopositioning applications require a "closed-loop" *position sensor* for feedback and control. Last but not least there is the command center of a positioning system, the *controller*, which can be digital or analog.

For nanopositioning manufacturers have several different categorization schemes, for instance, by function, such as push-pull actuators, movement along the linear x, x-y, or x-y-z axes, combined linear and tilt motions (θ-x/θ-y/z), focusing objectives or micrometer adapters. Each of these types may involve either closed- or open-loop architectures [Coffey 2010].

Flexure guided stages for nanosystems, by proper design, restrict each axis of the stage to move in only one direction, no motion in any other dimension. A flexure usually contains stiff flat springs to constrain the motion of a stage. [2]

As a summary, the positioning system is comprised essentially of four elements: a piezo actuator that provides motion, a mechanical translation mechanism (stage), a position sensor, and control electronics to maintain the desired position. To realize positioning with precision at nanometer levels these four elements need to be carefully designed and optimized.

The key is accurate position sensing and closed-loop control of the motion. Nanosystems' positioning devices have usually piezo actuators, and flexure motion control integrated into a single system. Stages with controlled motion in one, two or three axes are available, with virtually zero cross talk between motion directions.

Furthermore, usually special scanning probe microscopes (SPMs), atomic force microscopes (AFMs) or scanning near-field microscopes (SNOM) are needed for the nano-level (atoms, molecules) to see , for instance, atoms on a display [Runge 2014a] to track ultra-precise positioning.

> Correspondingly *suppliers in the nanopositioning market* cover suppliers of individual components or whole systems or both, suppliers of components and whole systems including accessories.

Growth of nanopositioning technology started in the late 1990s and picked up in 2003 - 2005. Currently, the growth rate of the market is assumed to be very high, probably around 30 percent (even 50 percent are given [Essays, UK 2013]).

Nanopositioning technology fits into the following major application markets.

- Semiconductor Lithography
- Microscopy
- Precision Machining.

A report [VDI 2004] estimated the global market for products of nanopositioning to be €0.5 - €1.0 billion in 2006. Taking for simplicity a year-on-year (YoY) growth rate of 30 percent one would estimate the market for nanopositioning to be €4.1 - €8.2 billion ($5.3 – $10.7 billion) in 2013.

On the other hand, a 2009-report [BMBF 2009] based on results of renowned US market research firms provided the following estimates of the market size for nanotools covering chemical vapor deposition (CVD), physical vapor deposition (PVD), lithography, and nanopositioning systems: $35 billion in 2008 and $43 billion in 2010 (growth rate 23 percent). Specifically the market for piezoelectric actuators and motors was given explicitly with sizes of $12.0 billion in 2008 and $15.3 billion for 2010 (growth rate 28 percent).

For lithography stepper (step & repeat system; projection printing) corresponding market data were: $8.93 billion in 2008 and $10.0 billion for 2010. Particularly, there is a market segment "Nanopositioning Systems for 3D Lithography Processes" [Physik Instrumente].

A 2012 technical market research report "Nanotechnology: A Realistic Market Assessment (NAN031E)" [BCC research 2012] valued the global market for nanotechnology at nearly $20.1 billion in 2011 and reported the market to reach $20.7 billion in 2012 with the segments nanomaterials (largest market), nanotools and nanodevices. Nanotools, accounting for ca. 30 percent of nanotechnology, should be valued at nearly $4.8 billion in 2012 and $11.4 billion in 2017 (CAGR [Runge:639] 19 percent).

Considering all weaknesses of the studies' methodologies, issues of forecasting and issues of definitions and segmentations of the field, one can cautiously say that in 2013 nanopositioning in a narrow sense is a market with a CAGR of 20-30 percent.

As seen referring to the R&D100 Award 2009 (Table 1) Attocube is active in the new field of Adaptive Optics (AO) [Wikipedia-1]. AO is a technology used to improve the performance of optical systems by reducing the effect of wavefront distortions: It aims at correcting the deformations of an incoming wavefront by deforming a mirror in order to compensate for the distortion (aberration-correction). AO can be used to improve the quality of any image, whether presented to the human retina or for further processing in other image capture systems (cf. R&D100 Award 2009 in Table 1).

A recent report [BCC Research 2014] gives a 10-year projection of the global market growth potential of adaptive optics systems in terms of AO revenues 2013 through 2022 for academic and applied researches along with military, medical, industrial, and consumer industries. AO is seen as a fast developing optical system technology, but is currently a complex system. The potential for system simplification and cost reduction has far-reaching implications and creates real commercial opportunities. Attocube is cited as one of the players in that field.

According to BCC Research [2014] the global market for AO systems reached $139 million in 2013 and is expected to grow to $157 million in 2014 (13 percent) and to about $40.7 billion in 2022. Military, as a segment, reached $81 million in 2013 and Medical, as a segment, reached $30 million in 2013.

Generally, military and US and European space agencies (NASA and ESA) seem to be important customers for nanoanalytics, nanopositioning and related components and systems. As usual for analytics (national) agencies working with industry to develop and apply technology, measurements, and standards are also potential customers. Defense applications include, for instance, nanopositioning guidance systems for unmanned drone aircrafts.

Awards and Publicity

Since its inception Attocube is a new technology venture highly awarded for its technologies and also commercial features and operations, whether as an independent NTBF or, after acquisition by the German WITTENSTEIN AG, as a medium-sized organization as given in Table 1 [Attocube].

Table 1: The continuous sequence of Attocube Systems' awards [Attocube].

	TOP100 Innovation Award Among the top 100 most innovative German medium-sized firms attocube made the No. 2 [Cluster Nanotechnologie 2013; CeNS – LMU 2013]. The TOP 100 Innovation Award honors outstanding SMEs (small and medium-sized enterprises) for their innovative strength and exemplary innovations management. attocube was one of them in 2013.
2012 R&D 100	R&D100 Award 2012 The R&D 100 Awards identify and celebrate the top technology products of the year. In 2012 the attoFPSensor received the so called "Oscar of Invention". With its high level of automation and ease-of-use software, the attoFPSensor is truly plug-and-play and does not require time consuming alignment procedures to get started. In addition to data transmission and storage on a personal computer through its USB interface the sensor is also capable of outputting virtually latency-free incremental and serial word position information at 10MHz bandwidth through its real time interfaces. Resolution, signal stability and band width of the attoFPSensor are compared to currently existing products [CLEO 2014].
	Deloitte Fast 50 The Deloitte Technology Fast 50 ranks the fastest growing technology companies (in Germany), based on revenue growth over the last five years. attocube received the prize in 2010, 2009 and 2008.

Table 1, continued.

	Bavarian SME Award The Bavarian Award for Medium-Sized enterprises (Bayerischer Mittelstandspreis – BVMW) is given to the most efficient Bavarian companies for their innovative products or services. attocube received the Award in 2009 with a second prize [BVMW 2009].
	IVAM-Marketing Award 2013 The award is given for extraordinary and creative marketing concepts in the microtechnology sector. attocube received the prize for its "attoDRY LAB" campaign. IVAM e.V. (Interessengemeinschaft zur Verbreitung von Anwendungen der Mikrostrukturtechniken Fachverband für Mikrotechnik): Being an international association of companies and institutes in the field of microtechnology, nanotechnology, advanced materials and optics and photonics, IVAM focuses efforts on creating essential competitive advantages for its members. It regards itself as a communicative bridge between suppliers and users of high-tech products and services in the above mentioned fields.
	CLEO/LFW Award Novel Fiber-Based Interferometric Displacement Sensor System attocube got the award for the development of an extremely compact, non-invasive, and multiple-channel interferometric displacement sensor system capable of detecting spatial position change of a device in translational motion with high precision. [CLEO 2014]. The CLEO/Laser Focus World Innovation Awards program is designed to honor the most timely, ground-breaking products in the field of photonics and laser science, here the attoFPSensor in 2012.
	Hermes-Award Top 5 The HERMES AWARD represents the core mission of HANNOVER MESSE – the promotion and celebration of technological innovation. attocube was amongst the Top 5 nominees in 2010 (http://www.neuematerialien.de/news/article_1648).
	R&D100 Award 2009 The Electron Microscope Stage — a device that enables atomic-scale imaging in 3D received the R&D100 Award in 2009. It was a joint project of LBNL and attocube scientists. Note that attocube opened its first US-subsidiary in Berkeley, California 2008. It refers to three-dimensional atomic-resolution tomographic imaging requiring analyzing a microscopic sample viewed from several directions, followed by a computerized reconstruction of the sample's 3D atomic structure by a Transmission Electron Aberration-corrected Microscope (TEAM). Developers were Lawrence Berkeley National Laboratory (LBNL), attocube, the FEI Company, and the University of Illinois at Urbana-Champaign [Berkeley Lab 2009; RDMag 2009].

Table 1, continued.

	Oustanding Entrepreneurs In 2008 attocube received two awards: The Munich and the German Award for Outstanding Entrepreneurs – The German Founders Award (Deutscher Gründerpreis) is one of the most prestigious prizes for startup companies in the country. Attocube won the Prize in the category “Climber of the Year.” [Deutscher Gründerpreis 2008a; Heflik 2008]
	Germany – Land of Ideas The landmark "Germany – Land of Ideas" is given to companies with imaginative flair, innovative products and a wealth of ideas. attocube was chosen to be one of these landmarks in 2008 [Land of Ideas 2008]. In 2008 attocube won additionally the Munich Founders Award associated with €5,000 [CeNS 2008].
	Bavarian Innovation Award (Bayerischer Innovationspreises 2006) This highly prestigious award is given by the Bavarian Government for outstanding innovative performance and is awarded every two years. In 2006 attocube received the award [Bayern 2006]. The Bavarian Innovation Award included also a monetary award of €50,000 [Universität München 2008]
INNOVATIONSPREIS DER DEUTSCHEN WIRTSCHAFT	German Industry Award The German Industry Innovation Award honors the most important scientific, technical, and entrepreneurial innovations of the German Industry. attocube was among the finalists in 2006.
PHILIP MORRIS STIFTUNG FORSCHUNGSPREIS	Philip-Morris Research Award The Philip Morris Research Prize is awarded to scientists for out-standing achievements. attocube was one of the nominees in 2004.
MBPW Münchener Business Plan Wettbewerb	Business Plan Competition In its founding year 2001 attocube received the award of the Munich Business Plan Competition which was associated with a monetary award of €25,000 and also premium networking opportunities. Furthermore, attocube was funded by the Bavarian Ministry of Science via the FLÜGGE program implemented at the University of Munich (LMU) [Universität München 2008]

According to Dirk Haft winning the German Founders Award “is the best thanks to our dedicated staff and invaluable for motivation. Public attention will reinforce our reputation, both in the founder’s community as well as in science.” [Deutscher Gründerpreis 2008a]

The Entrepreneurs

Attocube Systems AG was founded in November 2001 essentially by Dr. Dirk Haft (born 1969 in Munich, Germany) and Prof. Khaled Karraï (born 1962 in Saint Gaudens, France).

Dr. Dirk Haft studied physics in Munich and Orsay (France; part of University of Paris-Sud (University of Paris XI) distributed among several campuses in the southern suburb of Paris). He finished his study of physics with a PhD (Dr.) in 2001(Munich).

He was a member of the supervisory board of F&W Mobile Phone Systems AG 2000 until 2003 and is a member of the supervisory board of Catenic AG since 2010. In 2014 he earned a degree in Business Administration (St. Gallen, Switzerland) [Attocube].

Catenic AG, founded in 1999 and headquartered near Munich, develops and markets solutions for business planning, control and evaluation of global business services in the enterprise and the related service provider (IT and Shared Services organization).

For Dirk Haft a career as an employee was never an option. Actually, “since for Confirmation I got a Commodore 64, I am interested in computers. Even during student days I had a little IT company with one or two employees.” “I'm probably not the typical physicist and had a bit of fighting my way through the study of physics, because I wanted to be a patent attorney to go into the office of my father. For his office and other firms I have programmed databases while learning that you can get knocked down, if it does not work, but can earn decent money if it works.” [Jorda 2008; Deutscher Gründerpreis 2008a]

Even as a teenager Haft showed already a business mind. At 14, he invoiced resolving the computer problems of his father's patent law firm. "Being an entrepreneur, that's exactly what I’m after," said Haft. "It’s me to talk to technicians about how to build something. Or to get parts from all over the world." [Handelsblatt 2008]

Furthermore, according to Dirk Haft, “being an entrepreneur is with us in the family. My father was a freelance patent layer, and I had early a desire for self-employment. To sell something successfully has given me pleasure, and *also during my studies in physics I was always interested in how I can develop good ideas into marketable products*. Luckily during my diploma thesis I had a professor who supported me to develop marketable products from his concepts and who was also open to a possible firm’s foundation.” [Thiel 2008] (Emphasis added)

For Haft a good entrepreneur “has *specific goals* and pursues them consistently. As a consequence, that what you start you will bring to an end, even if it takes many years and you have to *overcome many obstacles* and *take risks*.” “Above all, *long-term thinking* and *perseverance* are qualities that experienced entrepreneurs show.” [Thiel 2008] (Emphases added) There should be *persistence* and *achievement*.

“As a founder above all you need *courage*,” said Haft and he got encouragement primarily by individual professors to start a company [Heeb 2008].

As a summary Dirk Haft has a strong business mind with distinct technical interest and competencies in physics and computer science. He represents a communicative “technical businessman” [Runge:118,190]. And he is a forward thinking person: "My mind is always working on where we will be in two or three years." [Handelsblatt 2008]

According to Dirk Haft Prof. Karrai “is an extremely astute researcher and has great ideas when it comes to the production of devices with simple handling.” [Vallaster and Kraus 2011:36].

Referring essentially to two references [Attocube; Technische Universität München] Khaled Karrai studied *Physics and Engineering* at the Institut National des Sciences Appliquées (INSA) in Toulouse, France. In 1984 he received his engineering degree from INSA and his diploma in physics from Université Paul Sabatier.

From 1984 to 1987 he had a research period at the High Field Magnetic Laboratory of the Centre National de la Recherche Scientifique (CNRS) and Max Planck Institute in Grenoble (Max-Planck-Intitut für Festkörperphysik, Stuttgart – Grenoble). Karrai was awarded his PhD in physics at Université Joseph-Fourier in 1987.

The next five years he worked as a research associate and an assistant research scientist at the department of physics and astronomy of the University of Maryland, USA. He came to the Technical University of Munich (TUM) in 1993 as an Alexander von Humboldt researcher and stayed until 1994 (group of Prof. G. Abstreiter and Prof. F. Koch).

From 1995 to 2006 Karrai was part of the Physics Department at Ludwig-Maximilians-Universität (LMU) in Munich as a Professor of Experimental Semiconductor Physics. He was also Guest Professor at the ETH Zurich (at the Quantum Photonics Group) and at the Institute of Advanced Science (IAS) of TU-Munich.

In 1998 he co-founded the Center for Nanoscience (CeNS) at LMU. This leads to assume Prof. Karrai to have communication and organizational talents and experience with writing project proposals.

In 2006 Prof. Karrai gave up his civil service tenure status (in German Beamtenstatus) and took over full-time the technical area of Attocube as the CTO and R&D head. Currently, he is Scientific Director at attocube systems AG.

Prof. Khaled Karrai was the first scholar who joined the Institute for Advanced Studies (IAS) at the TUM as a Rudolf Diesel Industry Fellow. The TUM-IAS Rudolf Diesel Industry Fellowship is designed for outstanding researchers from industry who would like to expand their connection to a TUM research group. It is the Fellowship's purpose to enhance collaboration and knowledge-sharing between research units at TUM and company research laboratories [Technische Universität München 2009].

Prof. Karrai never left the field of science entirely: "We work closely with research institutes, as our equipment is primarily for nanotechnology." With extremely precise positioning motors, the company has established itself internationally in the shortest time.

Professor Paolo Lugli, Professor of Nanoelectronics at the TU Munich, lured Karrai for the one-year scholarship in his research group at the TUM-IAS to work on "nano-imprint." Nano-imprinting refers to a kind of stamp that can characterize certain material.

"Nanoelectronics is Prof. Lugli's field, my expertise is nano-optics and instrument design in the field of extreme microscopy. I can contribute the experience of Attocube how to develop instruments that control the position of such tiny stamps and be able to apply forces with the utmost precision. We need to make it, if necessary, in a very controlled atmosphere or in ultra-high vacuum," said Prof. Karrai who envisioned his situation as an entry into further cooperation of attocube with TUM [Technische Universität München 2009].

Prof. Karrai has characteristics of an "entrepreneurial professor" [Runge:267,305]; he encourages firm's foundations [Von Randow 2004]. Karrai himself seems to have a business mindset as already during the 1990s he did not just go for patents but patented his findings often with a partner through a German legal general partnership GbR (Gesellschaft bürgerlichen Rechts) [Runge:228] as is fully spelled out in US patents (Dr. Khaled Karrai und Dr. Miles Haines GbR).

In the 1900s Dr. Haines was associated with the Walter Schottky Institute (focused on basics of semiconductor physics) of the Technical University of Munich (TUM) [Haines]. The mission of the institute is to strengthen exchange and transfer of pure science and applied science of semiconductor electronics. "Dr Miles Haines has practiced as a *patent attorney in Munich*, London and Southampton since 1992, obtaining full qualification as a UK and European patent attorney in 1999. He became a partner at D Young & Co in 2001. He specializes in physics-based technology areas including materials science. He has extensive *experience with company creation and development, especially from Universities*." [Haines] (Emphases added)

This GbR reflects Prof. Karrai himself to have an open mind towards entrepreneurship, specifically related to the commercialization of basic research.

Between August 1994 and December 1995 Prof. Karrai was Assistant Research Scientist at the Walter Schottky Institute (WSI) of the Technical University of Munich (TUM) [Vallaster and Kraus 2011:52]!

Business Idea, Opportunity, Foundation and Product Developments

The foundation of Attocube occurred by an entrepreneurial pair [Runge:191,306,328], both with the same basis of education in physics, but a very favorable collaborative constellation for entrepreneurship:

> There is one person with a clear vision and great praxis-oriented technical ideas and one person who pragmatically executes commercializing the ideas.

One reason that Attocube's founders (as also those of WITec [Runge 2014a]) started their businesses was that there was a *request for a "prototype product" associated with the purchase of this product* related to a promising idea at the Munich "Center for NanoScience" (CeNS) [Land of Ideas 2008].

"For about ten years, people tried to *assemble individual atoms* also *like Lego bricks* into something new," said Haft who has brought the nanopositioner to the market, a mini-motor. "What is the Otto combustion engine for the automotive industry, are those motors for nanotechnology," said Franz Gießibl, physics professor at the University of Regensburg. In particular, the semiconductor industry would like to use this effect to accommodate more and more circuits on a chip. Today's production with lithography techniques has limitations. And here Haft sensed his big chance [Handelsblatt 2008].

> Ultra-high precision spatial positioning of objects is a science central to most fields of nanotechnology.

But the question was how can researchers move from one sphere to the next with atomic-level precision? This is where Haft's titanium servo-motors, which are the size of a typical six-sided die, play an important role. The Attocube technology builds on positioning devices with moving parts even able to perform their job at ultra-low temperatures down to some milli-Kelvin (mK).

The idea was born in 1995 at the Center for NanoScience of the Ludwig-Maximilians-University. "At the LMU we dealt with optical spectroscopy of semiconductor quantum dots." [Haft 2004:3-5; Karrai 2007:10-11]. [4]

The challenges of the development work were (Haft 2004]:

- Resolution: Optic, sensoric, electronic, mechanics
- Positioning: Nanometer-precision, positioning path
- Environment: Very low temperature, highest magnetic fields and ultra-high vacuum. (UHV)
- Stability: Focus on an artificial atom over a time frame of several days.

Prof. Khaled Karrai soon realized the great potential for applications in Scanning Probe Microscopy (SPM). As one of his former PhD students, Dirk Haft got hooked and started thinking about founding a company [Attocube 2007]. Haft with some fellow students built SPMs under Karrai's supervision [Heflik 2008].

Actually the business idea for Attocube was developed while Haft was working on his diploma thesis. “Since we could not buy the necessary adjusters and build thereon scanning probe microscopes for low temperatures, we have developed them ourselves.” [Jorda 2008]

Specifically, Dirk Haft’s business idea reflects a generic origin of a business idea for an offering: “*Wanted as an individual consumer*” [Runge:Table I.46]. He was lacking a nano-microscope that works even under extreme conditions, for example, close to the absolute zero temperature. Then the molecules move much slower, what only makes some experiments at all possible [Dorn 2010].

As part of his diploma thesis Dirk Haft built a first prototype of the microscopes. "Visiting scientists or visitors kept asking where they could buy these devices. That's why I thought that there is more demand and drafted a business plan," recalled the founder. Also his supervisor, Professor Karraï, quickly recognized the potential of the idea and in 2006 even gave up his safe professorship to join totally the startup that was already operational [Deutscher Gründerpreis 2008].

But the very first great deal would have failed almost due to the administration. "A US professor wanted to buy a scanning probe microscope developed by Professor Khaled Karrai and me for DM50,000 (€25,000). Karrai wanted to make the money available to the university and to fund my PhD position for which he otherwise had no money. But the university blocked it." It took Haft three to four months to convince the administration that it is quite possible to charge funds from the private sector in a university budget [Deutscher Gründerpreis 2000b].

Hence, finally Haft could finance his position for the doctoral degree by the sale of a DM50,000 (€25,000) microscope to the American professor [Handelsblatt 2008]. Vallaster and Kraus [2011:36] report Haft to have received totally $50,000 for selling also a second prototype to an interested person in the US.

From this event a “market need” was inferred. “The products I developed as a student, met the interest of *many* visiting professors and over again. *Many wondered if you can buy one these* already, and so I knew that I'm on the right track and *the need in the market is available*.” [Thiel 2008] "Especially American guests have always asked: Where can I buy this," said Karrai. It dawned to Karrai that a profitable business was about to emerge [Heflik 2008] – with the US as an important *entry market*. A similar situation was observed for the foundation of WITec [Runge 2014a].

And Haft started *making plans*. “When visiting researchers wanted to buy these devices I perked up and began to make plans for an own company.” [Jorda 2008]

But he additionally performed his doctoral thesis: “Yes, but de *facto only* to do parallel the first steps for the company. Together with my supervisor Professor Karrai we had finished the first devices and sold them to low befriended researchers. Due to the positive feedback, we were motivated to write a business plan and to tackle the whole job professionally.” [Jorda 2008]

At the LMU Haft built an SNOM which required *staying power and persistence* [Runge:262]. For instance, he experimented with hundreds of piezo stacks until he found those which were precise enough for the nano-world (atoms, molecules) irrespective of the temperature of the environment and in an ultra-high vacuum as used for electron microscopes [Von Randow 2004].

Winning the Munich Business Plan Competition in 2001 (Table 1) convinced Haft to get seriously with the foundation of Attocube [Handelsblatt 2008] which could rely on *protection of the basis technology by patents*.

“The Munich Business Plan Competition has definitely helped to focus our business idea. In addition, we were able to make many contacts with coaches and business angels, who were very helpful to us. All this has given us a big boost. However, we had also founded without this competition.” [Thiel 2008]

Before Attocube's foundation reliable small positioning motors existed only as lab-built versions of researchers. One of these researchers was Prof. Karrai. "Karrai is a brilliant inventor, he had already *patented the mechanism of the servomotor*," Haft recalled (Emphases added). But the driving force behind the commercialization was his student Dirk Haft [Handelsblatt 2008].

The MBPW winning Attocube team had four members (Dirk Haft, Prof. Khaled Karrai, Hans-Jörg Kutschera and Christian Schäflein) [CeNS 2001]. After having won the Munich Business Plan Competition (MBPW) Attocube was partially funded by the Bavarian Ministry of Science [Universität München 2006].

Haft had begun with the development of first products at the Center for Nanoscience (CeNS). [Heeb 2008]. After its incorporation in November 2001 the young company continued the product developments in labs temporarily rented from the Ludwig-Maximilian-University, Munich (LMU) [Attocube 2007] on the basis of the FLÜGGE program of the Bavarian Government [Bavaria 2014]. The FLÜGGE program to support university spin-outs was also used by Nanion Technologies GmbH [Runge 2014c].

According to Vallaster and Kraus [2011:58] by June 2001 Dirk Haft and Attocube's first employee, Dr. Christoph Bödefeld, applied successfully for the FLÜGGE program.

After the official start of Attocube in November 2001 two people were working full time [Karrai 2007:8]. Two of the four co-founders had left the founding team very soon [Karrai 2007]. But this *dissolution of the team* did not affect the fate of the firm.

"I founded together with two fellow students with whom I could imagine a good cooperation. Today I know that it is not enough to be friends with each other. It is important that each partner has an entrepreneurial mindset and is ready to go personally into the risk. Unfortunately, that was not the case with each one, so that we have separated us again – luckily by mutual consensus. How important entrepreneurial thinking in a team is, we have also learned by the b*usiness angel, who is involved with us as an investor* and has longtime entrepreneurial experience. On his advice, therefore, each founding partner scored the same number of shares, but with the stipulation that one who is not committed by one hundred percent, again has to give up a portion of the shares." [Thiel 2008] (Emphases added) This angel investor (called business angel in Europe) played an important role for Attocube's development.

Attocube Systems AG was raised without any debt or venture capital, thus making the company independent and free in its way of working and thinking. Even without much money Attocube moved very soon to its own premises [Handelsblatt 2008].

In February 2002 Attocube Systems moved to new rooms at the Viktualienmarkt in the center of Munich (street address Viktualienmarkt 3). Already 15 months after being there, the production facilities were again moved to another, bigger place (street address Königinstrasse 11a) [Attocube 2007]. The fast move out of the university was intended "to face the reality of real costs." [Kararai 2007].

Only a few weeks later Attocube systems had installed their production facilities, development labs and offices in that ideal place not far from the physics department of the CeNS. The team included members with diverse backgrounds, such as semiconductor physics, mechanical engineering, electronic engineering or different fields of microscopy [Attocube 2007].

In 2002 the first full system was delivered and in 2004 the low-temperature confocal microscope "attoCFM" was introduced to the scientific world [cQOM 2012a].

First clients in the US, Japan, Korea, and Singapore (Figure 2) approved the success of the highly innovative technology and secured profits already in the very first business year paving the way for further growth [cQOM 2012a].

“We had black figures after eight months; however, we have also been working day and night," said Haft. “Our devices are the only ones in the market that work down to the absolute zero temperature under extreme conditions.” [Deutscher Gründerpreis 2008a].

Many of today's industries will experience major changes. In the future, it will become more and more important to position probes, samples, small tools or even whole devices on a nanometer scale. The team of Attocube Systems was prepared to develop devices that meet the related new market demands. The aim was to open *new possibilities* ranging from scientific and applied research to industrial applications, in particular, many OEM applications [Karrai 2007:25].

> The vision of providing the research market with a reliable, compact, nano-precise positioning system that is capable of executing sample movement from the sub-nanometer to a centimeter range even in a big variety of environments like UHV, low temperatures or at high magnetic fields was the fundamental *driving force for the young founding team* [Attocube 2007].

Since the company offers a *cross-sectional technology* with intelligent nanopositioning as the core a *fast and continuous growth* was envisioned.

Attocube’s flexible, low temperature microscope systems are based on its reliable positioning devices. Thus, as the microscopist on the macroscopic level can reposition his macro-objects or specimen essentially manually, the nano-level microscopist can perform *in situ coarse and fine positioning*, smooth scanning or automatically focusing any samples in respect to any probes at temperatures down to the milli-Kelvin (mK) range or under ultra-high vacuum conditions (UHV).

The beginning, however, was anything but simple. The time was "running with scissors," said Haft – although venture capitalists had ensnared him. "One even said: Take two million rather than the 600,000 envisioned in the business plan; then you grow faster." But then the “dot-com bubble” burst, and Haft did not get a penny. But there was a start with laboriously collected €100,000. "I wanted to know whether the company will be running or crashing," said Haft "and not languishing many years." [Handelsblatt 2008]

For the period 1999 to 2004 a rather detailed timeline of activities, product developments and launching, revenues and profits is given by Vallaster and Kraus [2011:58].

Production of Attocube’s offerings meant to a large extent purchasing lacking components from existing suppliers and assembling those with internally built components to the finished product. With increasing numbers of orders (Figure 2) this required in 2004 *professionalizing its procurement and production processes* and the introduction of first QM/QS Systems (*Quality Management*/Quality System). In 2005 the Kanban [3] production process was introduced [Karrai 2007] which is *controlling the logistical chain from a production point of view*, and is not an inventory control system.

A corresponding Quality Manager focused essentially on

1. Controlling and checking quality of the finished products
2. Compliance with given processes running (according, for instance, to ISO certification)
3. Tracking customer satisfaction.

And the *product line* of Attocube ranged from stand-alone nanopositioning components for laboratory applications to completely automated and integrated solutions for low temperature (LT) and UHV SPM species: Confocal Microscopy (CFM), Atomic Force Microscopy (AFM), Scanning Near-Field Microscopy (SNOM) and Scanning Tunneling Microscopy (STM) allowing operation modes down to 300 mK as well as high magnetic field and vacuum compatibility [Attocube 2007].

The basic key to the confocal approach is the use of spatial filtering techniques to eliminate out-of-focus light or glare in specimens whose thickness exceeds the immediate plane of focus. According to Wikipedia "Confocal microscopy is an optical imaging technique for increasing optical resolution and contrast of a micrograph by means of adding a spatial pinhole placed at the confocal plane of the lens to eliminate out-of-focus light."

The product range was completed by highly flexible control systems for multiple SPM (hard- and software) modules and software allowing 2D or 3D imaging. There are, for instance, piezo control electronics and fiber-optical interferometer for force microscopy. The piezoelectric, inertial motor stages allow precise alignment where manual access is undesirable or impossible. The handling allows "plug and move."

By 2006/2007 Attocube's nanopositioners were the only ones working reliable at temperatures near to the absolute zero, or in ultra-high vacuum – conditions required for chip manufacturing [Handelsblatt 2008].

Meanwhile Attocube employed 20 staff and earned more than four million euros (Table 3). Annual growth was 50 to 60 percent. Per week the Attocube technicians put together three to four motors with prices up to €8,000 (room temperature version), tailor-made; plus a complete scanning probe microscope for up to €300,000 [Heflik 2008]. Dorn [2010] gives a price of €200,000 for systems.

Just 25 large microscopy systems were built by Attocube per year [Dorn 2010]. And there were *no long product cycles* as, for instance, in the automotive industry.

The remarkable development of orders to Attocube during the period 2002-2006 is shown in Figure 2.

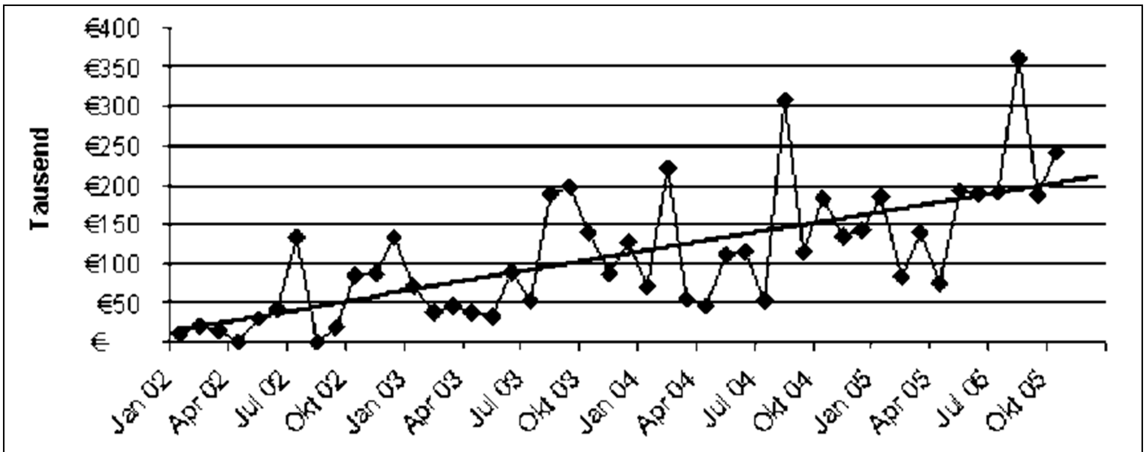

Figure 2: Attocube Systems: Development of orders 2002-2005 by months [Reineck 2007:24].

Attocube's two principal product lines in 2007 are visualized in Figure 3 and Figure 4:

1. Ultra-compact nano-precise *positioning devices* provide linear and rotational movement of samples or probes. Furthermore, nearly all of these ultra-compact titanium translation positioning stages can be specified for use under extreme environmental conditions (very low temperatures, UHV and magnetic fields). They are offered in different sizes and out of a variety of materials. The titanium motors are of the size of dices.
2. Various easy-to-use, highly flexible *low temperature Scanning Probe Microscopes* (LT-SPMs).

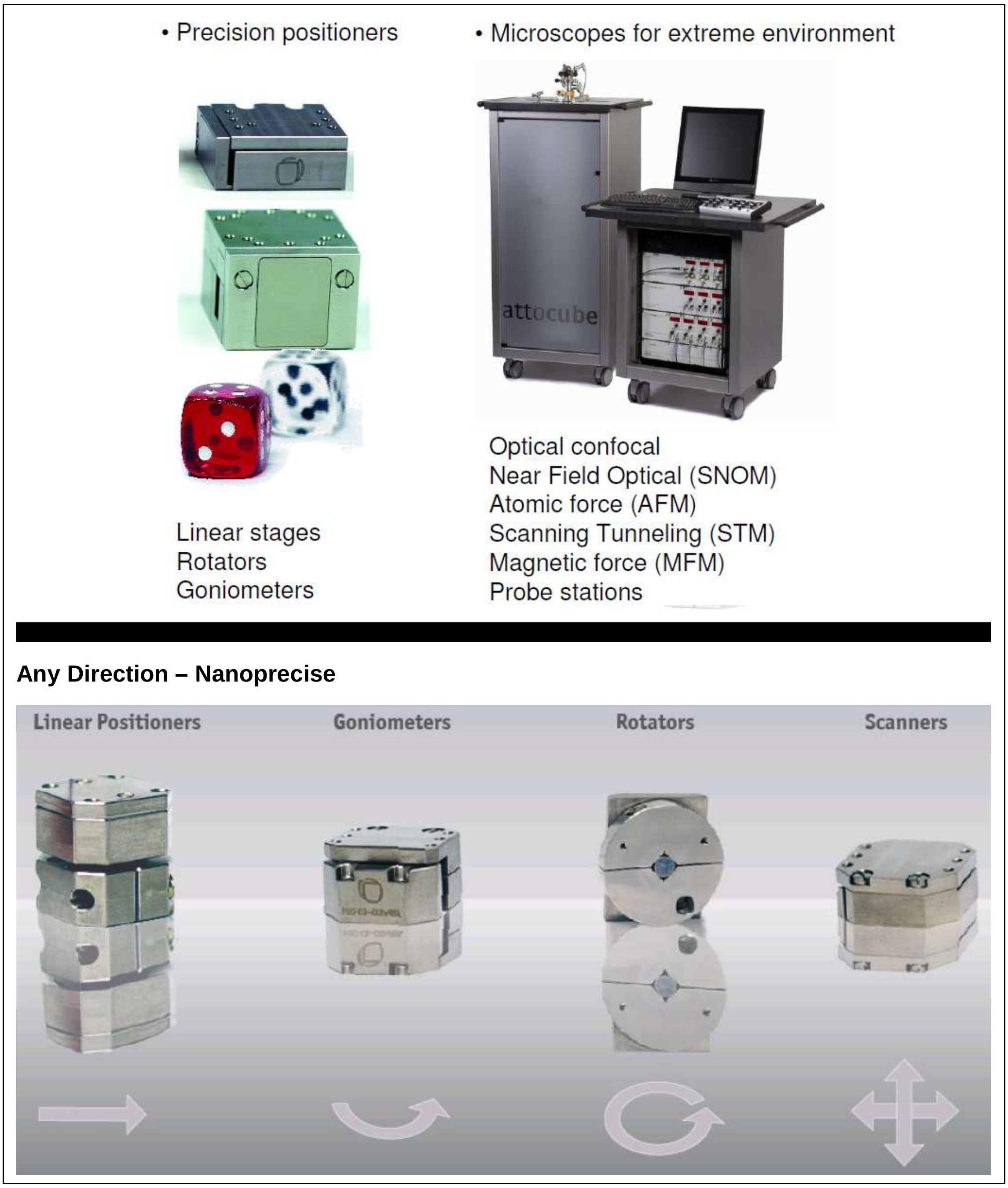

Figure 3: The principle products of Attocube [Karrai 2007:2,22].

The complement to Attocube's portfolio were the cryogen-free cooling systems which set new performance benchmarks and made possible what was considered impossible only a few years ago. Cryostats have been specifically designed to provide an ultra-low vibration measurement platform for cryogenic scanning probe experiments, without the need for liquid helium.

Then there are systems based on a liquid helium bath cryostat which had been optimized for highest stability. Such a system, allowing cryogenic measurements at temperatures as low as 100 mK, enabled, for instance, ultra-high resolution imaging using Scanning Tunneling Microscopy (STM) or long-term investigations of single quantum dots over several weeks [Attocube 2007]. The lowest base temperature to be achieved with such systems is 20 mK.

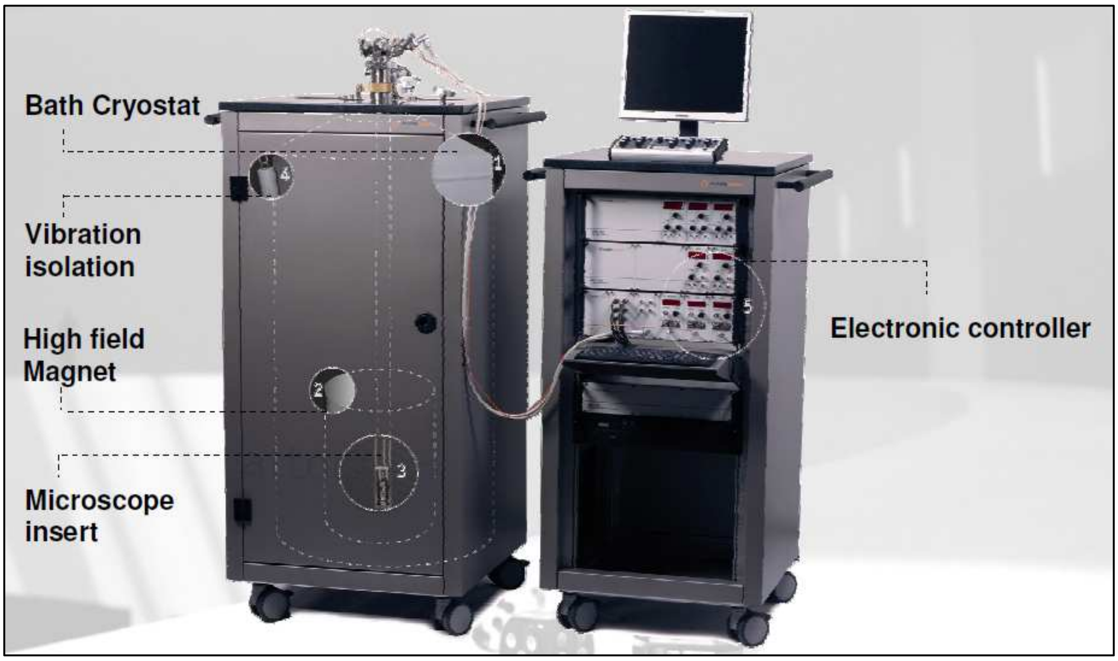

Figure 4: Cryostats as a product of Attocube [Karrai 2007:12].

“The recent successes are hard-won. Particularly it was (and is) *troubling keeping to constantly find new employees*,” said Haft – the demands are high [Handelsblatt 2008].

Corporate Culture

It was clear on foundation that intense cooperation is essential for the leadership team of the founders (Dr. Haft and Prof. Karrai) [Haft 2008].

Attocube is a highly interdisciplinary NTBF. Furthermore, it included members with diverse, also cultural, backgrounds. For instance, the basic structure of employees’ backgrounds was [Karrai 2007]:

- 6 PhD physics, chemistry
- 6 technical engineers
- 5 others.

This personnel would show up in industry mostly as “application scientists” or “application engineers.” Employees from other disciplines included IT-specialists, software developers, product developers and designers. And the (46) employees in 2013 were from 16 different nations [Yogeshwar 2013].

> Founders often play a key role in the company as they influence formatively the character of corporate culture and identity [Runge:659-665].

Behind the success of Attocube is a corporate culture in which *responsibility and trust* play an important role along with *excellent products* and *customer-orientation* [Thiel 2008].

“From the start we have highly valued *top quality*, not only in product development but in every respect. Therefore, it was important for us, for example, to relate to office space in a beautiful setting and not in any industrial area, so that we could also spatially offer an *attractive workplace* for our employees.

We have also established an *attractive salary* from the beginning, so that we *get high-caliber employees*. In order to achieve the highest quality, also human values, such as *trust and responsibility*, are important. I am willing to trust other people and *transfer responsibility* to my staff.” [Thiel 2008] (Emphases added)

“The other way round, I am always trying to be self-trustworthy and to act responsibly. These values are *the pillars of our corporate culture* and have *contributed much to our reputation and our success*. As every business is human-related customers do not only buy a product, but also business relationships and want to deal with people they can trust.” [Thiel 2008]

After all, Haft has no problem to *delegate* tasks [Handelsblatt 2008].

To build trust in Attocube’s *customer orientation* he said “Our motto is, ‘No is no option.’ This means that *we do everything possible to provide to each customer the best possible solution*. Therefore, we also accept orders, if we do not have the requested product. The risk here is with us, because the customer pays only when he gets the product delivered and is happy with it. Satisfaction alone is not enough for us*. Only when the customer is happy with what we offer him, we have done our job well.* This attitude has brought us a lot of good word of mouth and correspondingly new customers.” [Thiel 2008]

Attocube’s customer relationship reflects the role of “the customer as the innovator” as is observed also for the other related startups (WITec, JPK Instruments). According to Haft and Karrai [Yogeshwar 2013]:

> “In our industry, the customer does not decide according to price but solely on who is the most innovative one and can offer the latest.”

This means, developments are executed with a *sense of urgency*, often following “rapid prototyping” – completing the finished product together and in accordance with the customer from the public R&D environment. Correspondingly, researchers from universities or public labs are not so critical or sensitive towards the “level of perfection” when they get an “alpha test device.” This may be due to the fact that the specification for the device by the user was incomplete and that the exact ultimate specification can only be obtained by further experiments.

This approach resembles the “minimum viable product (MVP)” concept of Eric Ries from 2011 (author of The Lean Startup) for commercialization of enabling technologies and related products used in the scientific community, such as the scientific instruments community.

Industrial customers, however, are much more sensitive to such factors; they want to get “really finished products” for their money – and are also ready to pay more for the products.

Attocube’s corporate culture determines the *innovation climate* of the firm and trust in employees is the basis of *innovation culture*. This means employees can act independently and get creative freedom. To innovate Attocube targets to be open minded and flexible in its work. The well-managed organization utilizes a *forward-thinking culture* that is *always seeking to improve*.

Getting the best results is about sharing responsibility at every level within the company. *Leadership and initiative* are qualities encouraged at Attocube. With its growing global presence Attocube draws on the most talented people from a wide range of backgrounds and education [Attocubbe 2007].

At Attocube *dialogue* is a vital part of the working day. *Communication channels* between all team members are always open, ensuring that any problems are dealt with swiftly and effectively. Passion and pride are emotions common among Attocube people: passion about the jobs they do and pride in the product they create [Attocubbe 2007].

There is a guarantor for Attocube’s good innovation climate, the principle of being “godfather for your own ideas.” This means, the creator of an idea, which is implemented, may always remain close to his/her “baby.” The person accompanies the development process of the novelty, presents it during fairs and exhibitions and will be integrated into the marketing strategy. Being the “godfather of a product” is inspiring. [Yogeshwar 2013].

Furthermore, employees from research or production may also participate in customer visits. “Here they learn first-hand what they can improve on their products,” explained Haft. Such a way of interconnecting own research personnel to customers is also an explicit strategy of Nanion Technologies [Runge:2014c].

The above outline indicates that even as a 100 percent subsidiary of WITTENSTEIN with a new owner Attocube has essentially kept its corporate culture [Yogeshwar 2013; CeNS 2013]. All this was the basis to provide a “TOP100 Innovation Award” (Table 1) to Attocube.

Attocube’s *location* in close neighborhood to the Munich University (LMU) means that Attocube is often visited by researchers with whom Attocube’s employees discuss and share information and ideas. But the most valuable sharing for Attocube occurs during exhibitions and conferences, where they meet their competitors. “In the industry, we do not see ourselves as competitors, we tend to cooperate rather than to work against each other.” [Yogeshwar 2013].

For instance, scanning near-field optical microscopy (SNOM) is the outstanding technique to simultaneously measure the topography and the optical contrast of a sample. And, under the heading NANOSCOPY, Attocube developed its attoSNOM I, for which one can see that a “competitor” (WITec; Table 6) may act as a supplier:

> “The experimental setup of the low coherence interferometric system: A laser beam is coupled into a single mode fiber which guides the light through a 50/50 coupler directly to a specially prepared SNOM cantilever (*Witec system*).”
> “The attoSNOM I works by scanning a cantilever in the optical near-field of a sample surface. This *microfabricated SNOM sensor, distributed by WITec*, consists of a silicon cantilever with a hollow aluminum pyramid as tip.”
> “The attoSNOM I is an easy-to-use system that combines the advantages of SNOM and AFM in a single instrument which is highly suitable for applications under extreme environments such as low temperature and high magnetic fields.” [NANOSCOPY]

And correspondingly, though confocal Raman microscopes are a strength of WITec [Runge 2014a] Attocube launched the attoRAMAN Confocal Raman Microscope (CRM) which, however, is a designated *low temperature* CRM. It combines a high resolution low temperature confocal microscope with ultra-sensitive room temperature Raman optics. This enables state of the art confocal *Raman measurements at cryogenic environments combined with magnetic fields of up to 15 T* [NANOSCOPE].

The approach to cooperate with the related global scientific community to identify new requirements or problems of the technology and the markets and from that develop related innovative solutions is very explicitly described for JKP Instruments [Runge 2014b] in terms of a computer-based tracking system.

Financing, Networking, and Organization

For their startup the founders decided in favor of a private stock company (“Aktiengesellschaft” AG) as such a legal form of the firm allows to get investment capital easier than an LLC (GmbH) and, furthermore, employees’ salaries may get a stock option.

The 2001/2002 Dot-Com Recession interfered with plans of how to finance foundation. “We had a plan B, with which we have grown till today completely based on own cash flow – no bank loans and risk money.” [Jorda 2008] “We did not want to burn money for years and then enter the market with a product, but from the beginning we wanted a much targeted customer contact. The bursting of the Internet bubble was a cautionary tale for us,” said Haft [Deutscher Gründerpreis 2008a].

As mentioned above the incorporation of Attocube Systems was in November 2001 and initial financing was based on €100,000. Half of it was provided by the founders and the other €50,000 by the business angel Stefan Reineck [Sparkasse Iserlohn 2013].

The history of Attocube is full of various financial transactions, beginning with the sales of the technical prototype and the Munich Business Plan Competition (Table 1) for the start of the firm. Participation in a business plan competition did target initial financing of Attocube [Jorda 2008].

According to Vallaster and Kraus [2011:37] in summer 2002 Stefan Reineck organized a loan of €100,000 which was necessary to fulfil existing product orders (cf. Figure 2). This loan was already paid back by the end of 2003. This means, Attocube achieved early financing essentially without external capital (no long-term loan or venture capital).

According to the author's knowledge there is no public information available in how far utilizing the FLÜGGE program was used also in terms of financial aid. FLÜGGE usually provided financial support ("salary for living") and options to use university infrastructure for necessary developments [Runge 2014c].

The congratulation of the Munich Savings Bank (Stadtsparkasse München) to its customer Attocube Systems AG for the first place in the German Founders Award 2008 in the category Climber [Stadtsparkasse München 2008] indicates this savings bank to play a role for Attocube – perhaps for short term loans or agreed upon levels of overdrafts for a corresponding account [Stadtsparkasse München 2008]. The Munich Savings Bank was definitely helpful to conduct business abroad [Haft 2009].

For the development of Attocube the business angel Stefan Reineck contributed more than just money. Prof. Karrai [2007:8] acknowledged the "very sound guidance and advice from our business angel."

Concerning Reineck Haft explained: "He was the first investor, of all we contacted, who really *listened*. All others have told us, what we should do, however, *without understanding what we do and where we want to go.* That we then chose this business angel as an investor, had to do with his behavior towards us. His willingness to listen, influenced our corporate culture for sure. Meanwhile, we have established a friendly relationship, which has an additional positive effect on our cooperation. Above all, I am glad that I can *talk* with him *about particular entrepreneurial perspectives and visions*, and *he stays out of our daily business*." [Thiel 2008] (Emphases added)

The human qualifications are seen by Haft to be the real added value.

"An investor should not only be a financier, but he must also accompany human the company. Therefore, it is important that *he understands both the relevant founders and the founding process*. He must understand *how the founders think* about where they want to go and *what ability they have for that*. If he still can also complement the lacking know-how of the team this is also very helpful." [Thiel 2008] (Emphases added)

In the context of entrepreneurship it is worthwhile to deal with the personality of Stefan Reineck as a business angel [Zoominfo; Reineck 2006; Reineck 2007; Marsh 2003].

Dr. Stefan Reineck (born 1952) received his doctoral degree in physics at the Technical University of Darmstadt and has extensive experience in semiconductor and data storage device manufacturing.

He began his industrial career at Leybold AG (for 12 years in Germany and the US), an international plant construction company for the semiconductor and data storage industry, where he ultimately held the position of Division Manager for Data Storage Technology Facilities. He subsequently assumed management control of KVG Quartz Crystal Technology GmbH (for 8 years), a small-to-medium-sized manufacturer of equipment for the telecommunications industry.

From 2002 to 2006, he served as Spokesman of the Management Board of STEAG HamaTech AG, which specializes in the production of optical storage media and photomasks.

After leaving this position, he became a management consultant (Managing Director of RMC Dr. Reineck Management & Consulting GmbH) [Reineck 2006; Reineck 2007]. From April to September 2007, Dr. Reineck was an interim member of the Management Board of SUSS MicroTec AG before joining its Supervisory Board in October 2007. SUSS MicroTec is a leading supplier of process equipment for microstructuring in the semiconductor industry and related markets. He is currently Chairman of the Venture Forum Neckar.

At the end of 2006 Dr. Reineck was involved in the following NTBFs/startups where he was a member of the supervisory boards and comparable domestic and foreign boards of directors.

- Attocube Systems AG, München
- NanoScape AG, München: Nanomaterial, nano-particles
- Crystal GmbH, Berlin: Laser and high-precision crystals
- Wafer Masters Inc, San Jose, California, USA: Equipment for the semiconductor industry
- TFI Instruments, Heidelberg: Ultrasound diagnostics for pharmaceutical products
- NovaWaveLight GmbH, Martinsried: 3D sensors, image identification and image processing.

After Attocube had been acquired by WITTENSTEIN AG Dr. Reineck became a member of the WITTENSTEIN Supervisory Board.

From his presentation entitled "*Motivation and success factors of a business angel engagement*" [Reineck 2007] we learn about Dr. Reineck's motivation to act as a business angel (BA):

- Shape (the new venture), transfer know-how
- Enjoy to see the growth
- Joy on latest technical developments
- Be commercially successful.

But in the end "it must be fun." [Reineck 2006]

Dr. Reineck [2007] strives for the following success factors for high-tech firms and for his role as a BA he matches them with his own competencies (Table 2).

Furthermore, Table 2 exhibits how an appropriate BA can contribute to a success of a new technology venture.

Table 2: Factors and contributions to the success of a technology startup with the help of a business angel [Reineck 2007].

Success factors: • Technology/Innovation • Management, • Market • Financing	Relevant know-how covering: • Market • Technology • Business model • Operational
The startup's basis is usually incomplete and related competencies are lacking – at least partly	

Table 2, continued.

A startup's needs for success according to Reineck's views	Success for BA and venture:
Team: CVs, complementary competencies, completeness Business proposal: • Product, market, team, organizational structure Potential for realization: • Chances, barriers, risks	• Formal and binding agreements • Consortium-like treaty: binds BA and founders • Commitment of the founders • Share available in special situations ("take along") • Supervisory board or similar committees with rules

Attocube is generally looking for long-term partners and stable cooperation. Already in 2003 Attocube introduced CRM/EPR systems (Customer Relationship Management/Enterprise Resource Planning).

As described above *cooperation and networking* with the worldwide scientific community (universities and public research organizations) and customer orientation are essential for Attocube. Correspondingly, Attocube established targeted cooperation with international special *suppliers*. They all represent *important external resources*.

Strategic cooperation partner included [Haft 2008]:

- Lawrence Berkeley National Labs (LBNL), Berkeley USA
- VeriCold Technology, Ismaning (Germany, near Munich)
- TUM Technische Universität München (Germany)
- CeNS, Center for NanoScience, LMU München (Germany)
- TU/e, Technische Universität Eindhoven, Eindhoven (The Netherlands).
- Kern Feinmechanik, Murnau (Germany, not too far away from Munich)
- CIA Cryogenic Industry of America, Manchester, USA (now Cryo Industries)
- Janis Inc., Boston, USA.

The *international* networking of Attocube provides a substantial increase of know-how [Haft 2008]. The feedback from professionally sound product reviews of the customers of the global research community in science and industry allowed Attocube Systems, after the foundation soon recognized worldwide as a specialized competence center and *being part of the worldwide research community*, to continuously identify requirements, to develop and implement solutions immediately with the support of a tight network of regional suppliers into new products [Haft 2008].

Thanks to Attocube's solutions new insights are generated and implemented globally as innovative technologies [Haft 2008]. This role of "*the customer as the innovator*" is also found with the other SPM NTBFs and is described in more detail for JPK Instruments [Runge 2014b].

Karrai [2007:8] characterized these kinds of customers by the statement: "Several customers 'friends and fans' in the scientific community." Being part of the research community is observed also for the other SPM NTBFs [Runge 2014a; 2014b] essentially via their well-known CTOs with high academic reputation and, hence, acceptance by their peers in the research community.

Specifically, for Attocube a technological implementation for an individual case often induced a notable demand from the globally networked research laboratories and provided the profound growth by its own resources [FhG-IAO 2011].

Referring to Attocube being an accepted and renowned part of the worldwide research community Karrai [2009] described this special role of Attocube as follows:

> Knowledge of fundamental research topics is often decades ahead of applications. This means a long period passes before early results of basic research initiate industry involvement. There is a fundamental disconnection of the two worlds.
>
> Sometimes, however, it is suitable and even possible to involve an industrial activity at a very early stage of research if the scientist's awareness be raised and addressed in time. And attocube's emergence can be seen as an example bridging the gap between the two worlds.

Attocube even advises researchers who are looking for new microscopy techniques, develop new devices and assemble them. And the experience and skills of Attocube's R&D employees is rather profound. Moreover, "for us, the physicist still solders him-/herself," said Haft, not without pride [Dorn 2010].

Soon after foundation Attocube addressed actively the biotech area. "Nano researchers do not want only to see, but also to change," said Haft. "With a kind of tweezers our motors can already hold individual polls with a size of several micrometers. Biologists in the future could also move syringes extremely accurate in cells." With the Faculty of Medicine in Hamburg there was a project in which researchers wanted to extract individual cells from tissue and examine them. "Diseases could be detected early and drugs developed more quickly," hoped the company's founder [Heflik 2008].

Attocube participated also pro-actively in joint projects (in German Verbundprojekte) funded by the Federal Ministry of Education and Research (BMBF). For instance, in the area of biophotonics in its early life Attocube was a partner in the joint project "Live Cell Screening" funded with €2.5 million (funding period: May 1, 2005 – Apr. 30, 2007) [Haft 2007; BMBF 2005]. Networking was between partners from opto-electronics and electro-mechanical industries (TILL Photonics, Attocube and ibidi GmbH), the biotech firm ProCorde GmbH and universities, LMU Munich (BioImaging Center), University of Freiburg and the University Hospital Hamburg.

Particularly the semiconductor industry is interested in nanoproducts, said Haft. "The vision is to be able to move single atoms selectively and in masses. Then you could build, for example, fine lines and storage structures," atom by atom. In this way the storage space for a bit, the data unit, may shrink by one hundred thousand, processors would be smaller, more economical and faster. "It will take a while until this happens, but also for the road to that goal our products will be in demand," added Haft [Heflik 2008].

After five years of existence and loose organizational structure according to activities in 2005 Attocube had more than ten employees and in line with the "10 – 25 – 150" rule [Runge:656-659, Table I.72], it changed to a new organizational structure [Haft 2008].

As usual a very young technology spin-out with an innovative corporate culture emphasizing roles rather than defined jobs relies often initially on agreed upon responsibilities and employees look for additional responsibilities to establish their overall field of responsibilities. And smart people usually will grasp almost unlimited responsibilities. This may form a sort of skeleton for an emerging organizational structure of the new firm in terms of functions and jobs.

Six years after foundation Karrai [2007] presented Attocube's organizational structure in terms of two business units (BUs), "Research Instrumentation" and "Industry" (Figure 5). But the complete organization can probably be represented similar to Novaled's early matrix structure (Figure 7 in the related case [Runge 2014d]) with the common functional units of technical firms given in boxes.

The unit NANOSCOPY covers as options different types of microscopes: AFM, SNOM, CFM and STM. Customized products which often require further development work of Attocube could be characterized as attoSOLUTIONS.

Basically there are functions dedicated to a particular BU and those that extend over the two BUs. The examples of some "job titles" of the corresponding units' members illustrate tentatively functions and job titles which were found on the Internet, particularly on the Web sites of the professional social networks Xing (Germany) and LinkedIn (US).

In the course of Attocube's further development the below BU-structure evolved into one given in Table 5.

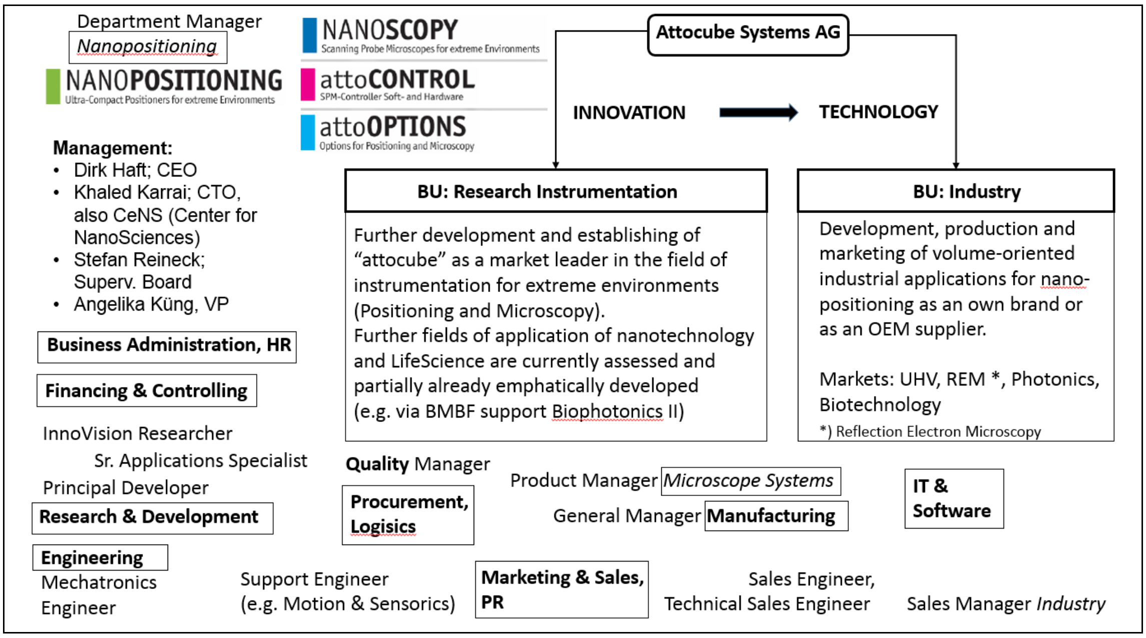

Figure 5: Organizational units (in boxes) of Attocube at ca. 2007 and selected roles or titles, respectively, of functionally different employees [Karrai 2007].

As a stock company Attocube had to report company specifics according to legal requirements and that was obviously done carefully. In 2007 there was the first voluntary attestation by auditors providing a highly positive assessment: "Reporting, organization, data management and company documentation exemplary, despite being a very young company!" [Haft 2008]

External organizational structures refer to external offices or subsidiaries of Attocube, distributors and partners – targeting enduring partnerships with its customers, supporting suppliers and cooperative partners.

The company focuses on segment-oriented marketing and networked distribution structures, serving customers at their locations and with extensive quality control.

With the US scientific sector having become a more and more important market for Attocube, the company opened its first US-subsidiary in Berkeley, California in 2008 (followed by a second one in New York City in 2012) and 2009 in the UK [Dorn 2010]. However, after four yours Attocube Systems Ltd. was dissolved (incorporated 16 Oct 2008, dissolved 2 Jul 2013).

In 2007 the regional proportions of customers were [Karrai 2007].

- US 40 percent
- Europe 35 percent
- Asia 25 percent.

The structure of customers in 2008 illustrated by some well-known examples was:

- Universities and public research institutes
  Stanford University and MIT, California Institute of Technology (CalTech), ETH Zurich
- German and US standardization organizations
  PTB (Physikalisch-Technische Bundesanstalt, BAM) and NIST (National Institute of Standards & Technology)
- European Research Laboratories in Grenoble, Munich, London and CERN (European Organization for Nuclear Research)
- US and European space agencies, NASA and ESA
- Large technology firms like IBM, HP, Toshiba, JEOL and Carl Zeiss.

More customers are listed by Karrai [2007:5].

Only seven percent of attocube's 2009 revenue of €6 million stemmed from Germany [Dorn 2010].

Worldwide distribution, sales and support have been developed and organized (by 2012) in the following way:

Europe is served by the headquarters in Munich/Germany Two offices in the US: attocube systems Inc. (Berkeley, CA; New York, NY – West Coast and East Coast), a distributor in Brazil	Distributors in Asia: • China • India • Japan • Korea • Singapore • Taiwan

Innovation Persistence, Expansion and Being Acquired

The successful development of Attocube experienced a first significant bracket [Runge:708-734] when the German firm WITTENSTEIN AG took 74 percent of share of the company by September 2008 (since then named attocube systems AG) [Attocube 2008]. In the business year 2011/2012 WITTENSTEIN increased its share in attocube to 100 percent [EB].

In order to boost further growth and to benefit from synergies with a strong commercial and technological partner attocube and WITTENSTEIN AG – a Germany-based high-tech company – started a *strategic* partnership in 2008 [cQOM 2012a].

"With WITTENSTEIN we have found a technologically and economically strong partner that enables our company to make greater use of the world's existing opportunities and thus to accelerate growth," said Dirk Haft [Attocube 2008].

If micro-semiconductors, called nano-chips, will be made in several years by mass production, Haft wants to participate: "Then we want to supply to the 'big' ones {firms}." In the medium term attocube's systems could be built in series in the WITTENSTEIN works [Dorn 2010].

According to CEO Dr. Manfred Wittenstein "attocube is an outstanding company of world leaders in technology, whose products open for us the door to the nanoworld." And he expected that nanotechnology in combination with other technologies will conquer new markets world-wide and products and manufacturing processes in many industries will be revolutionized [Attocube].

Dr. Haft and Prof. Karrai kept their management positions and attocube's supervisory board also kept Dr. Reineck complemented by Dr. Wittenstein and Dr. Bernd Schimpf (also of WITTENSTEIN AG).

By 2008 WITTENSTEIN AG (with 1,600 employees and revenue of €164 million in 2007) is a high-tech company with a national and international reputation of “innovation, precision, excellence” in the field of mechatronic drive technology. The WITTENSTEIN Group included (at that time) seven innovative businesses as separate units. In addition, WITTENSTEIN had approximately 60 subsidiaries and representative offices in about 40 countries in all major markets of the world. Its basic orientation is towards intelligent mechatronic drive systems and an integration of micro and macro technologies. WITTENSTEIN is an award-winning company in the field of innovation and personnel policy [Attocube 2008].

WITTENSTEIN has an export rate of ca. 60 percent; ca. 10 percent of revenue is invested in R&D and ca. 12 percent of the employees are in R&D. In the business period 2013/2014 WITTENSTEIN had 1,800 highly qualified employees, and a yearly turnover of €250 million [Wikipedia-2]. And there is the claim: “attocube & WITTENSTEIN – a perfect match.”

Considering that Haft basically did not want to be an employee and Karrai wants to continue being and acting as a scientist one can speculate that there are special personal agreements between Wittenstein and Haft and Karrai on their and attocube’s future statuses and their freedom to act and decide – irrespective of financial aspects for the two co-founders.

If Haft and Karrai would leave attocube it would not just be a loss of established scientific and business leadership, it could also mean that the two key persons would take along several of attocube’s employees – key researchers and sales personnel with customer-facing experience – to probably found a new own firm.

Furthermore, WITTENSTEIN would lose the scientific network of both which is a key asset for further innovation. Hence, also keeping attocube’s original location as a subsidiary very close to LMU and CeNS is a reflection to keep attocube and its relevant physical and intellectual environments intact.

Finally, there may be also issues of ownership of key patents (Table 4) if Haft and Karrai would leave the firm.

There is the cautionary tale for acquisitions in the scientific instrumental community – the Digital Instruments (DI) – Veeco – Asylum Research Corp. case [Runge 2014a:Figure 5].

Following the attocube-WITTENSTEIN event a further takeover occurred with similarities to the attocube case [GEN 2012; Nanotech-Now 2012; Photonics 2012].

DI (founded in 1987) was taken over by Veeco Instruments in 1998, but in 1999 several former DI-employees founded the employee-owned Asylum Research Corp. – conveying “the double entendre in its name that it would provide an asylum for disaffected Veeco employees.” Asylum is headquartered in Santa Barbara, CA.

At the end of 2012 Asylum with subsidiaries in the UK, Germany, and Taiwan was taken over by Oxford Instruments Plc for up to $80 million (an initial debt free, cash free consideration of $32.0 million with a deferred element of up to $48.0 million payable over three years dependent on its performance over that period [Nanotech-Now 2012]).

This figure provides some basis to estimate roughly how much the attocube-WITTENSTEIN deal was worth totally (covering acquisition in two steps).

Asylum Research makes scanning probe and atomic force microscopes for academic and industrial customers in materials and bioscience applications. During 2011 Asylum Research generated $1.1 million in earnings before interest and tax on revenue of $19.6 million (ca. €15 million) during 2011.

Asylum Research claims to be the AFM technology leader and to offer the lowest cost of ownership of any AFM company with the industry-best five-year warranty.

“Asylum Research – an Oxford Instruments Company” said in its own statement that it would remain in Santa Barbara and keep its current management, led by co-founders Dick Clark, the company's CFO; Roger Proksch, president; and Jason Cleveland, CEO.

"The acquisition of Asylum Research significantly increases our footprint in the nanotechnology space and complements our strong position in electron microscopes with a presence in another fundamental nanotechnology measurement technique," said Oxford Instruments CEO J. Flint. "The acquisition also gives us access to the rapidly growing bio-nano market, as it allows customers to perform analysis of organic samples in their natural liquid environments, something which cannot readily be done using electron microscopes." [Photonics 2012]

"Our passion for science has always been at Asylum's forefront," co-founder Cleveland said. "Partnering with Oxford Instruments will allow us to do an even better job at bringing instrumentation to scientists for discoveries that will ultimately lead to amazing innovations." [Photonics 2012]

"We are very excited about joining Oxford Instruments," commented Dick Clark, co-founder and Chief Financial Officer. "The synergies between our companies is extensive and we're looking forward to joining this elite company that has proven leadership in the scientific instrumentation business," added Roger Proksch. "It was clear from the beginning of our talks that Asylum Research and Oxford Instruments both share the same core values while providing world class customer support and service, and making the most technologically-advanced instruments. We are looking forward to joining their team and getting the best AFMs to scientists faster and with even more capabilities." [Nanotech-Now 2012]

It is interesting to note that Oxford Instruments acquired also one of attocube’s strategic partners, VeriCold Technologies GmbH. [5]

During the years following 2008, attocube’s success story continued, obviously in the same style as “before WITTENSTEIN.”

For instance, in 2009, attocube launched the world’s smallest, real-time interferometric sensor, the “attoFPS.” The attoFPS received the R&D 100 and CLEO Laser Award (Table 1) demonstrating its impact on semiconductor and other industry sectors [cQOM 2012a].

So far, for the absolutely precise measurements of distances the relative motion was measured by the deflection of a beam of light. However, this process is disadvantageous due to the limited size of the mirror mechanics and susceptibility towards disturbances. attocube removed the mechanics totally and generated the very tiny sensor which utilizes the various spectral waves of light in a glass fiber for distance measurement [FhG – IAO 2011].

Only one year later, the attoDRY1000 – the world’s lowest vibration cryogen-free cooling system – was introduced to the market followed by the cost-effective, industrial line of nanopositioners “attoECS”, released in 2011 [cQOM 2012a].

In the context of the WITTENSTEIN Group attocube also professionalized its marketing approaches which is reflected by winning the IVAM-Marketing Award (Table 1).

The IVAM Prize was for an integrated marketing campaign for the product line attoDRY LAB, including a slogan ("Cool down. Measure. Publish"), a design concept with logo development and the efficient implementation of the campaign using various marketing tools, such as thematically ajar fairs in the corporate design of the campaign as well as means of social media communication [IVAM 2013; Attocube 2014].

Whereas so far concerning conditions the emphasis was on the vacuum and temperature environments (UHV and very low temperature) attocube was also addressing magnetic properties of materials and high magnetic fields especially by two products. Magnetic imaging on the nanoscale was developed in terms of magnetic force (MFM) and scanning Hall probe (SHPM) microscopy.

As described on its Web magnetic imaging on small length scales has long been an important asset in fundamental research of various magnetic materials and superconductors. The attoMFM I and attoSHPM are to be seen complementary: SHPM provides the user with a non-invasive, quantitative measurement of the local magnetic field, whereas MFM is sensitive to the gradient of the local force but with almost an order of magnitude higher in spatial resolution.

And also public perception of attocube under the roof of WITTENSTEIN continued.

The Bavarian Award for Medium-Sized Businesses (BVMW) is given to the most efficient Bavarian companies for their *innovative products or services*. attocube received the Award in 2009 with a second prize. And in 2013 it entered the TOP 100. Among the top 100 most innovative German medium-sized companies attocube made the No. 2 (Table 1).

attocube also continued to participate in publicly funded projects, for instance, the EU-project Cavity Quantum Optomechanics (cQOM) funded with €5,717,364 in the context of Networks for Initial Training (ITN) [cQOM 2012b].

cQOM shall bring the quantum regime of mechanical oscillators (utilizing mechanical oscillators coupled to laser fields) in reach and may allow to explore new fundamental measurements concepts, which may lead to novel transducers and test quantum mechanics on a macroscopic scale (cf. last patent of Karrai in Table 4).

Furthermore, cQOM is a field which is highly faceted in terms of the required and offered training skills that spans quantum optics, nanofabrication, finite element simulation and cryogenic expertise and techniques as well as quantum theory.

“The distinguishing feature of this ITN training network is that the partners are active in this research field (cavity Optomechanics), which facilitates and indeed leverages the collaborative effort and will make this ITN highly effective. This training program will be of immediate benefit to the partners that will thereby obtain a superior training of their PhD students, which therefore provides a build-in mechanism that will ensure the effective realization of the proposed ITN training program and its success.” [cQOM 2012b]

Particpants with coordination by the École Polytechnique Fédérale de Lausanne (Switzerland) include

Universität Wien Austria,

Gottfried Wilhelm Leibniz Universität Hannover Germany

Université Pierre et Marie Curie - Paris 6 France

Centre National de La Recherche Scientifique (CNRS) France

Universiteit Gent Belgium

Friedrich-Alexander-Universität Erlangen-Nürnberg Germany

Universita Degli Studi di Camerino Italy

IBM Research GmbH Switzerland

attocube systems AG Germany

Very recently for its growth efforts attocube also turned to a *non-organic growth path*. In early 2014 it acquired the majority holding in NeaSpec GmbH [NeaSpec 2014]. “Neaspec and attocube share a common history and the same values: They have been founded as spin-offs from prestigious research institutes (CeNS & Max-Planck-Institute), are passionate in developing excellent products, and enabling applications close to the limit of what is physically and technically feasible.”

According to Haft “Neaspec’s sophisticated products and their first-class technical know-how ideally complements our existing portfolio. This offers the opportunity to expand our innovation leadership in the long term and to secure further growth. We are looking forward to a fruitful cooperation and many inspiring ideas to come."

Prof. Karraï, also showed delight about the new partnership: "Neaspec is the perfect partner for attocube. The award-winning NeaSNOM is doubtless one of the most elaborated SNOM systems currently available on the market and is the ideal base for benefitting from emerging technological and personnel-related synergies. Together with Neaspec we will definitely develop pioneering innovations in the future."

NeaSNOM is claimed to be the only microscope in the market capable of imaging and spectroscopy in the visible, infrared and even terahertz spectral region at only 10 nm spatial resolution. This makes NeaSNOM the ideal tool for cutting-edge nanoanalytic applications.

Key Metrics

According to Karrai [2007] Attocube had an export rate of 80 percent in 2007 and had delivered more than 1,500 positioners and more than 30 systems.

Its original entry market was non-industrial R&D customers. The distinct growth of orders shown in Figure 2 is also reflected by attocube's increasing numbers of all types of customers:

- 350 customers in 2005 [Bayern 2006].
- More than 450 customers in 2007 [Karrai 2007] (probably 500)
- 900 customers in 40 countries in 2012 [Sparkasse Iserlohn 2013].

attocube builds just 25 large microscope systems per year – *almost exclusively custom-made* according to specific customer requirements. Dirk Haft and his colleagues visit around 40 international congresses and fairs annually [Dorn 2010].

After foundation in November 2001 attocube achieved its breakeven after six months – without any loan or venture capital. Since then attocube was never in the red.

First clients in the US, Japan, Korea, and Singapore approved the success of the highly innovative technology and secured profits already in the very first business year paving the way for further growth. In 2002 attocube started the "regular" production of low temperature positioners and scanning probe microscopes [cQOM 2012a].

attocube's development in terms of revenues and numbers of employees is given in Table 3. It is not clear whether and in how far attocube integrates public grant money into its revenue.

Table 3: attocube's revenues and numbers of employees per year.

Year	**Revenue (€, mil.) a)**	**Employees b)**	**Reference and Remarks**
2001		{1}	
2002	0.37	{2} 2	[Vallaster and Kraus 2011:58; Karrai 2007]
2003	0.87	{4}	[Vallaster and Kraus 2011:58; Karrai 2007]
2004	ca. 1.6	{7} 10	[Karrai 2007; Von Randow 2004]
2005	2.0	{10} 15	[Bayern 2006, Karrai 2007]
2006	ca. 2.8	{14}	[Karrai 2007]

Table 3, continued.

2007	4 (extrapolated)	{18} 20	[Karrai 2007]
2008	4,5 5.0	{25} 25	[Deutscher Gründerpreis 2008a] [Land of Ideas 2008]
2009	6	35	[Dorn 2010]
2010			
2011	Almost 10 million, 7.5 million (!); 9.25 million c)	40	[Sparkasse Iserlohn 2013; Statista; FhG – IAO 2011]
2012	ca. 10	46	[Yogeshwar 2013; WITTENSTEIN 2013]

a) Revenues 2002- 2006 also from Karrai [2007], b) number of employees in braces are from [Haft 2008], c) cf. below text.

Revenue data given in the literature for 2011 are perplexing. The jump of €3 million from 2009 to 2011 in two years (roughly 30 percent per year) is – in the author's opinion – very remarkable considering the Great Recession during that period. Hence, revenue of €7.5 million seems to be more likely.

However, in [cQOM 2012a] one reads "Up to now, attocube has registered a permanent growth well above market average, reaching 25 times the turnover of its founding year 2001" (likely meaning 2002 after foundation in November 2001; Karrai [2007:7] shows no revenue for 2001, cf. also Figure 2). Then using the 2002 revenue data provides revenue of €9.25 million, in favor of the Sparkasse Iserlohn [2013] number. Finally, WITTENSTEIN [2013], as a reliable source, characterizes the 2012 data as ca. €10 million in the context of "an average growth rate of 20 percent" of attocube. Hence, ca. €8 million should be the likely value for 2011 revenue.

Intellectual Properties

Already in 1995 Prof. Karrai – one of the founding members of the Center of NanoScience (CeNS) – realized the great potential of positioning devices able to perform at ultra-low temperatures. He widely patented that basic technology and started development work with PhD students, particularly Dirk Haft [cQOM 2012a]. Patenting activities were actually between 1994 and 2001. Only the WO-patent from 2001 (attocube's year of foundation) has also attocube as a patent assignee.

A selected list of Khaled Karrai as an inventor or patent owner and/or attocube, collected from the database of the European Patent Office (EPO), is given in Table 4. As mentioned above Prof. Karrai did not just go for patents but patented often his "pre-attocube" findings with a partner through a German legal partnership GbR (Gesellschaft bürgerlichen Rechts) as is fully spelled out in US patents (Dr. Khaled Karrai und Dr. Miles Haines GbR).

Dirk Haft as the inventor shows up twice in the below table.

The given list of patents demonstrates (again) the focuses of attocube's offerings: positioners and position detectors, interferometers, SPMs and SNOMs and sample holders and imagers.

Table 4: Selected patents or patent applications of Attocube or its founders (from the European Patent Office (EPO) database).

Inventor	Title (Assignee)	Patent No./ Legal Status	Priority Date
	Absolut-Entfernungs-Laserinterferometer (Absolute distance laser interferometer) (attocube systems AG [DE])	EP20130169159	2013-05-24
Karrai Khaled Braun Pierre-Francois	a, b) Device for acquiring position with confocal Fabry-Perot interferometer (attocube systems AG [DE])	EP20100153054	2010-02-09
Karrai Khaled [DE]	a, b) Apparatus for determining a position (attocube systems AG [DE])	EP20070019476	2007-10-04
Haft Dirk [DE]; Lindenberg Tobias [DE]; Boedefeld Christoph [DE]	a, b) Positioning device with a fixed-body joint (attocube systems AG [DE])	DE20051026708	2005-06-09
	Submillimeter accuracy positioner for cryogenic container use sends modulated light to and from optical grid modulator over optical waveguide (attocube systems AG [DE])	DE20051022876 DE20052020928U	2005-05-18 2005-05-18
Haft Dirk [DE]; Sqalli Omar [DE]	Sub-micron positioner with optical determination of location comprises first and second modules moved relatively, with laser source, optical modulator and optical fiber connections (attocube systems AG [DE])	DE20051022876	2005-05-18
Karrai Khaled [DE]; Bickel Florian [DE]	Method for the production of a probe tip, particularly for near-field optical microscopy, having a desired aperture (Univ Muenchen L Maximilians [DE]; Karrai Khaled [DE]; Bickel Florian [DE])	DE2001164093	2001-12-24
Karrai Khaled [DE]; Haines Miles [DE]	a, b) Inertial rotation device (Karrai Khaled; Haines Miles, attocube systems AG)	WO2001EP13632 GB20000028511	2001-11-22 2000-11-23
Karrai Khaled [DE]; Warburton Richard [GB]	Laser (Karrai Khaled [DE]; Warburton Richard [GB])	GB20010008291 20010403	2001-04-03
Karrai Khaled [DE]	a, b) Sample holder apparatus (Karrai Haines GbR Gesellschaft [DE])	GB19980014144	1998-06-30
Karrai Khaled; Manus Stephan	Scanning probe microscope (Karrai Haines GbR [DE])	EP19980102250 EP19970301658	1998-02-10 1997-03-12

Table 4, continued.

Karrai Khaled [DE]; Manus Stephan [DE]	a) Scanning probe microscope head with signal processing circuit (Khaled Karrai und Dr Miles Haines Ges)	US19970827216 GB19940009414 US19950395089	1997-03-28 1994-05-11 1995-02-27
Karrai Khaled; Manus Stephan	Near-field optical microscope (Karrai Haines GbR [DE])	EP19970301657 EP19970301658	1997-03-12 1997-03-12
Karrai Khaled Dr. [DE]	a, b) Inertial positioner (Karrai Haines GbR [DE])	GB19960016456 GB19970005374 US19960024024P	1996-08-05 1997-03-14 1996-08-16
Karrai Khaled [DE]	a) Far-field characterization of sub-wavelength sized apertures (Khaled Karrai und Dr Miles HaInes [DE])	EP19950106900 EP19950108673	1995-05-08 1995-06-06
Karrai Khaled [DE]	a) Coupled oscillator scanning imager (Khaled Karrai und Dr Miles Haines [DE])	GB19940009414	1994-05-11

a) Patents mean that for the related patent/application a granted US patent exists; b) the patent belongs to a patent family with more than two members.

Concerning patenting strategy the inventions of the (identified) six patent families of attocube or Prof. Karrai with more than two members are regarded as particularly important for the firm. In Figure 6 it is shown in which specific countries patenting occurred. Apart from the World (WO) and European (EP) patents/applications which may comprise several EP countries ("designated states") one can see that for the non-European countries – as expected – the US and Japan (JP) are significant. For Europe Germany (DE), the UK (GB) and Austria (AT) emerge.

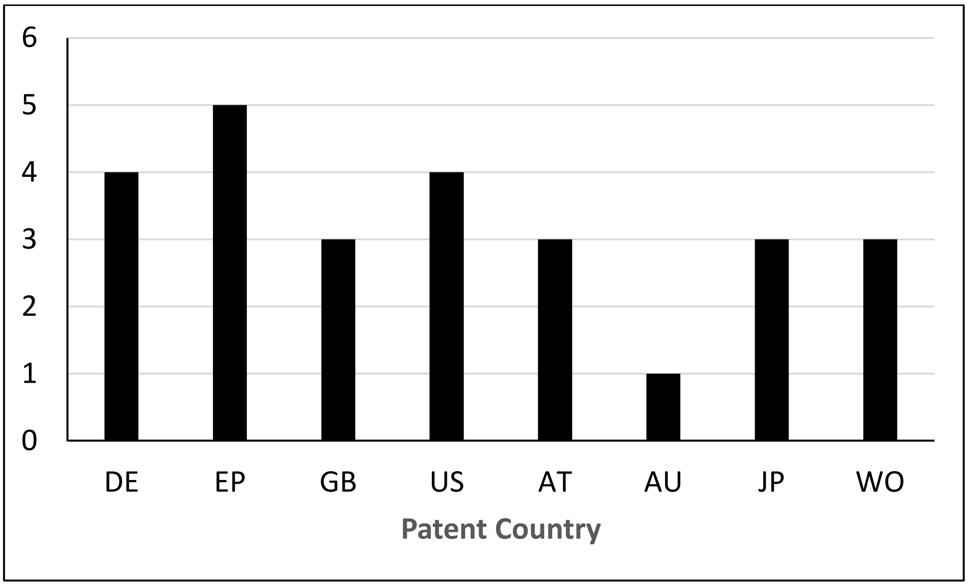

Figure 6: Major designated states for patenting activities of attocube (or Khaled Karrai).

Vision, Mission, Business Model and Risks

As WITec [Runge:2014a] attocube was launched without venture capital and its development was essentially funded entirely from rising, value-driven sales.

A vision of providing the research market with a reliable, compact, nano-precise positioning system that is capable of executing sample movement from the sub-nanometer to a centimeter range even in a big variety of environments like UHV, low temperatures or at high magnetic fields – at the physical limit of what is technically feasible. – was the driving force for the founding team [Attocube 2007].

According to a modified vision an *innovation driving concept* was born with attocube to provide a simple, adaptable and cost-effective system for research and industry [Bayern 2006]. attocube had always been ambitious in developing visionary products and challenging the *status quo* in ultimate precision and is still doing so.

By type attocube is involved in an *enabling technology* [Runge:129] which simultaneously represents a *cross-section technology*. Future industries envisioned for attocube's offerings included semiconductors/chips, biotechnology, new materials, communication and aviation and aerospace industries and it can be assumed attocube to open and occupy many market segments guaranteeing growth [Haft 2008].

The *product portfolio* as the basis of a *revenue model* comprises *integrated system solutions* as well as *single components*, including cryostats (Table 5, Figure 4), for use in science and industry which includes *OEM* (Original Equipment Manufacturer) *customers*. In addition there is a revenue stream generated by *customized systems* via "contract development" which would be attoSOLUTIONS.

The term OEM is used in several ways Here OEMs are manufacturers who resell another company's product under their own name and branding. If, for example, Hewlett-Packard (HP) sells circuit boards to Acme Systems for use in Acme's security systems, HP refers to Acme as an OEM.

attocube's basis is *customer-orientation*: "It is more important than ever for the vendor to understand the user's application." [Karrai 2007] Simultaneously, attocube builds on relationship with a business partner. "Trusted to Deliver Excellence" is the fundamental philosophy. And it is internalized that its customers will be looking at it expecting attocube to deliver the best in service solutions. "When we do, we build enduring relationships with our customers and our partners." [Attocube 2007]

While for R&D a wide and flexible range of applications and specifications for systems with specialist users exist industrial production and quality control require easy operation and interfacing and require integrating features for the manufacturing process.

Concerning microscopes similar to JPK Instruments which is focused on BioSPMs [Runge 2014b] attocube emphasizes a *differentiator,* extreme environments for measurement and observation – and additionally manipulation of nano-objects.

Currently, belonging to the WITTENSTEIN Group, attocube describes itself on its Web as "the partner of choice for research laboratories and OEM customers all over the world. The close cooperation with the scientific community is the foundation for our success. It creates unique synergies of pioneering ideas and turns them into products perfectly tailored to the requirements of today's challenges in the nanotechnology world. The product portfolio comprises integrated system solutions as well as single components for use in industry and science."

As a part of WITTENSTEIN AG attocube's original motto – pioneers of precision – has found an equivalent expression: "attocube & WITTENSTEIN – a perfect match – Innovation. Precision. Excellence."

Plotted against WITTENSTEIN's business units one observes that attocube's business activities provide often favorable complements to WITTENSTEIN's BUs (according to its Web site) – not on the macro- or micro-, but related to the nano-level.

<table>
<tr><td></td><td>WITTENSTEIN alpha
Specialist for mechanical drive solutions: low-backlash planetary & servo right-angle gearheads as well as complete drive units.</td><td rowspan="7">attocube systems AG
Fully integrated solutions for most challenging nanotechnology applications in ambient & extreme environments</td></tr>
<tr><td></td><td>WITTENSTEIN cyber motor
Customized motors for increased productivity and longest service life, suitable for use under extreme environments.</td></tr>
<tr><td></td><td>WITTENSTEIN electronics
Highly reliable electronic and software components for complex mechatronic drive systems, tailor-made support.</td></tr>
<tr><td></td><td>WITTENSTEIN motion control
Electromechanical servo systems demonstrating the highest level of controllability, precision, functionality, reliability and durability</td></tr>
<tr><td></td><td>WITTENSTEIN bastian
Innovative gearing technology solutions, always considering the unique requirements and specific needs of different application areas.</td></tr>
<tr><td></td><td>WITTENSTEIN intens
Experts in innovative medical technology solutions, focusing on intelligent implants, such as the unrivaled FITBONE®.</td></tr>
<tr><td></td><td>WITTENSTEIN aerospace & simulation
Powerful actuator systems satisfy the need for maximum effect, efficiency, and minimum weight in aerospace industry.</td></tr>
</table>

Hence, attocube's current central *mission* is to "deliver uniquely precise, elegant, and reliable products, thus solving the emerging challenges in worldwide nanotechnology applications. We are passionately curious in all we do and strive to surprise our customers with easy-to-use, highly functional solutions, facilitating their day-to-day work."

The structure of the *current product portfolio* includes ultra-precise drive units and highly sensitive interferometric displacement sensors solving highly accurate measurement tasks in micro-material processing, optical industry applications as well as in the semiconductor and life-science markets (Table 5).

Table 5: The structure of attocube's current product portfolio [Attocube].

attoDRY LAB Fully automated, cryogen-free nano-characterization platform with a variety of different measurement options.	attoCRYO Dry & liquid cryostats, optimized for most sensitive measurement techniques at variable temperature & high magnetic field.
attoMICROSCOPY Measurement inserts for nano-characterization of surfaces & bulk materials at low temperatures & high magnetic fields.	attoMOTION Piezo-based nanopositioners for research & industry applications. Suitable for ambient to extreme environments.
attoSENSORICS Ultra precise optical sensors for real-time displacement and vibration measurement with picometer resolution.	attoCONTROL Electronic & software control units: Advanced control electronics and software modules for attocube's nanopositioners and microscopes.

Distribution *channels* for attocube's offerings (at least until the end of 2008) included essentially two paths. For applications and market areas with given requirements standard (OEM) products like nanopositioners were usually distributed by known distributors. The R&D market was essentially delivered via direct sales. WITTENSTEIN's role for distribution and sales is not clear.

According to Vallaster and Kraus [2011:44,56-57] during attocube's early phase for applications in the ultra-high vacuum the company Hama (Vorarlberg, Austria) acted worldwide as a distributor.

In particular, microscope systems running under extreme conditions, due to their complexity of assembling and handling, were directly dispensed to the R&D labs. As will be described below feedback of R&D users to attocube's developers is a key component for attocube's innovations.

In particular, Figure 5 (lowest right) reveals that concerning sales there are special requirements to be taken into account for industrial customers.

Concerning key partners, *suppliers and customers*, gaining visibility and customer *relationships,* there is close similarity with WITec GmbH and JPK Instruments AG [Runge:2014b:26-28] and shall not repeated in detail here. For instance, a JPK School or WITec Academy now shows up as the attoAcademy.

In the WITec and JPK cases marketing and customer relationships include the following aspects:

- Gaining visibility
- User Education and Training
- Customer Contacts.

Customer and market-orientation is a *success factor of attocube* associated with extensive quality control and contact with customers in their locations. Trust and mutual sharing of knowledge bestowed the name attocube systems an excellent *reputation* in professional circles [Haft 2008]. The company strives to provide targeted marketing campaigns and networked distribution.

For all *suppliers*, the focus is on flexibility to operate in line with the market and customer friendly. And there was an emphasis on suppliers from Munich and its near environment. During attocube's early phase these included, for instance, Ertl Feinmechanik, Laux Präzision

München GmbH for precision mechanical parts, and Elatec GmbH (Haar near Munich) for electronic components and as a distributor for semiconductor producers. These suppliers were able to produce larger quantities [Vallaster and Kraus [2011:38].

Customers as key partners reflect for those from science the principle of “the customer as the innovator.” This is due to the fact that attocube is regarded as a part and specialized competence center which is appreciated worldwide by the relevant scientific communities.

There is feedback from professionally sound product reviews of the R&D customers of the global research community in science and industry who get their attocube systems usually directly and installed with the help of attocube R&D/technical personnel. And this allows attocube to continuously identify requirements and to develop and implement solutions immediately into new products [Haft 2008].

attocube regards its *Unique Selling Proposition* (USP; in German Alleinstellungsmerkmal) to be interconnections of ideas, their realizations, success and anew innovation (“innovation persistence” [Runge:625,628, Figure I.117]). R&D on the highest level provides results which are fast transformed into products demanded worldwide by top labs. Fed into science, education and industry new knowledge thus achieved facilitate progress and future viability [Haft 2008].

When attocube was incorporated the co-founders were convinced of successful growth due to their USP described above and additionally to a perceived bright future:

> If micro-semiconductors, called nano-chips, will be made in several years by mass production, Haft wants to participate: "Then we want to supply the ‘big’ {firms}." In the medium term attocube’s systems could be built in series in the WITTENSTEIN works [Dorn 2010].

But already in the first half of 2004 Haft saw a related risk [Von Randow 2004]:

> Eventually, chip producers and other large companies will need exactly such techno dice as they are produced by attocube, actually in masses, cheap and extremely reliable. At the latest then the question arises whether someone helps Haft to make his ten-man operation up a hundred-man operation.

In particular, the large German firm Physik Instrumente (PI, Table 6) could emerge as such a threat which until so far represented a competitor just for the OEM arena and measurements under “normal” conditions.

And already in 2003 when profiling Stefan Reineck Marsh [2003] wrote about Reineck’s angel investments: “Attocube's long-term progress will depend at least partly on its ability to form links with larger machinery and engineering groups.”

Due to the independence from venture capital Haft and Karrai were free from any pressure to grow explosively. Therefore, the “strategic partnership” with WITTENSTEIN in 2008 seemed be the response to these considerations of Haft. This appears as “risk transfer” at a probably non-monetary cost for the founders.

As a general risk the rate of sales into the industry segment will depend on in how far and fast attocube succeeds in transforming use of their systems for academic researchers into systems regarded as straightforward and easy to use by non-specialists for more or less routine operations (cf. Figure 3 in [Runge 2014b]).

Education and training of talented people is a specific marketing tool of attocube and creating a stock of future potential employees – considering the lack of specialists in this area as risk.

As describe above for an EU project cQOM in the context of “Networks for Initial Training” (ITN) recently there started a further EU-project in this line, S^3NANO – Few Spin Solid-State Nano-

Systems (from 2012-01-01 to 2015-12-31) funded with €4,000,024 [S^3NANO 2012]. The network brings together a strong group of world leading experts in nano-science and technology in order to achieve breakthroughs in understanding and successful utilization of nanoscale systems in future devices. The focus of the related consortium is on few spin nano-systems in solid-state materials including III-V semiconductors and carbon-based structures: carbon nanotubes, graphene and diamonds.

The network is about to deliver top international level multidisciplinary training to 11 early stage researchers and 5 experienced researchers, offering them, in particular, an extended program of multinational exchanges and secondments (detachment of a person from his or her regular organization for temporary assignment elsewhere). R&D will undertake a broad scope of tasks important for implementation of spin nano-systems in future devices, such as non-volatile ultra-compact memories, nano-magnetometers, spin qubits [6] for quantum information, and high-efficiency single photon sources. Participants under coordination of the University of Sheffield include

The Chancellor, Masters and Scholars of the University of Cambridge UK	Eidgenössische Technische Hochschule (ETH) Zürich Switzerland
Technische Universität München Germany	Universität Basel Switzerland
Universität Konstanz Germany	Technische Universiteit Delft Netherlands
attocube systems AG - Germany	Leiden Cryogenics BV Netherlands

WITTENSTEIN Group generally supports university research in mechanical engineering and machinery and nanotechnology. Particularly, the attocube Research Award honors outstanding, highly motivated students of CeNS of the LMU and/or the Walter Schottky Institute (WSI; focused on basics of semiconductor physics) of the Technical University of Munich (TUM) who performed excellent research in the framework of a Master's or PhD thesis showing strong innovative ideas and pointing at potential industrial applications. [7]

Two prizes will be awarded:

- €2,500 for completed Master's Thesis
- €5,000 for completed PhD Thesis.

In addition to the prize for the applicant, the supervising laboratory of the PhD student will receive twice this prize money, €10.000, for supervision of a PhD Thesis.

Competition

Generally, NTBFs targeting scientific instruments and being more or less tightly integrated into the scientific community show a rather free flow of information and sharing of knowledge – and even commercial knowledge.

As described above this is expressed by Dirk Haft:

> "In the industry, we do not see ourselves as competitors, we tend to cooperate rather than to work against each other." [Yogeshwar 2013].

As attocube (founded 2001) produces and sells as one branch SMPs operating under normal conditions it is clear that with its birth there was a number of firms – large ones and small NTBTs – that were already active in the field, in particular, new firms founded between 1997 and 2001 [Runge 2014a:Figure 5].

However, if the competitors do not manage to bring suitable low temperature and UHV fit products on the market, attocube system would remain the only supplier in this field. Otherwise, it may occupy a market leading position through its technological advantage and global networks.

The customers in the R&D segment can be divided into two categories: On the one hand, there are organizations which must position nanotech objects exactly on a nanometer scale at low temperatures and/or UHV and thus run microscopy at low-temperature, for instance, the semiconductor and chip fields and probably also magnetic materials. On the other hand, there are organizations which focus on normal temperature and perhaps low vacuum conditions – those dealing with "soft" materials of biotechnology and life sciences including medicine.

Derived from lists of exhibitors of physical societies' meetings, APS (and DPG in braces), or information by Coffey [2010] the leftmost column of Table 6 shows SPM suppliers (already given in the WITec case [Runge 2014a]). The remaining two columns exhibit firms which, by their focus on nanopositioners and related components and SPMs plus complements and accessories, could be potential competitors of attocube, particularly in the OEM field.

nPoint and Mad City Labs, both localized in Wisconsin not far away from each other and founded a little bit earlier than attocube during the 1997-2001 period, provide a similar spectrum of offerings and services as attocube, with an emphasis on OEM products.

Additionally the large German Physik Instrumente (PI) may be a threat. Physik Instrumente (PI) was (and is?) an important supplier for JPK Instruments [Runge 2014b], for instance, concerning PI's piezo nanopositioning systems.

Ritter [2005] describes in detail how Physik Instrumente operated in the US at two locations with 20 people with a focus on nanopositioning, nanoscanners, piezolinear-motors etc. to build SNOMs.

But for these firms, attocube's instrumentation allowing *operation under extreme conditions* provides a differentiator. Especially with regard to PI attocube may have a competitive advantage due to the focus on operations under extreme conditions *and* via its flexibility and speed in development of *customized products*. But there may be notable competition with PI with regard to OEM products.

Nanonics Imaging only claims to have developed a low temperature SPM system. But specifically for attocube's recently launched magnetic force (MFM) and scanning Hall probe microscope (SHPM) Nanomagnetics Instruments appears as a direct competitor in this specific field and it allows also low temperature microscopic investigations.

All the above mentioned firms have representatives, distributors or offices, respectively, worldwide or in selected key countries.

For the OEM scene Sigma Koki Group (Tokyo) with its product lines "Manual Stages", "Motorized Stages" and "Actuators" and "Optical-Mechanics & Manual Positioners" and "Optics" businesses may play a certain role for the Asian markets. It addresses applications in R&D and production equipment.

It is interesting to note that nPoint Inc.(incorporated as Piezomax Technologies, name changed in 2002) had Max G. Lagally, the (entrepreneurial) Erwin W. Mueller Professor and Bascom Materials Science and Engineering Professor of Surface Science at the University of Wisconsin-Madison, as a co-founder [University of Wisconsin-Madison 2010].

In a lecture Prof. Lagally described "one path that parallels the evolution of research in nanoscience. The path leads from scanning tunnel microscopy studies of the motion of atoms on Si surfaces to Ge nanostructures (quantum dots) fabricated with atom-by-atom deposition methods." [Lagally 2012]. That means Lagally had scientifically the same origin, quantum dots, as Karrai to focus on nanopositioners. In related scientific publications both are often cited simultaneously in the same publication ("co-citations") and they probably know of each other.

On the other hand, two physicists, William O'Brien and James MacKay, co-founded Mad City Labs. "Together they had spent decades building instruments at academic and government labs and also worked at the Madison nanotech firm now known as nPoint.” "They were very flexible and eager to catch a market that others didn't really want to address." For nanopositioners they cited the dominant German firm Polytec PI as a competitor [Stein 2005].

And also nPoint stated that its “primary competitors include Physik Instrumente of Germany [SolidStatePhysics 2003].

Both NTBFs did (and also currently do) utilize for their developments financial support (grants) of the US Small Business Administration (SBA) and its SBIR/STTR programs [Runge:156,207-208], but received also rather regularly money from governmental organizations (federal grants/awards and also purchases), such as the Department of Defense (DoD; DARPA – Defense Advanced Research Projects Agency) or Department of Commerce. Their end users include both military and commercial customers.

But for nPoint and Mad City Labs Prof. Lagally said “he also sees space in the market for both companies to grow.” [Stein 2005].

Table 6: An extended list of companies offering SPMs running under normal conditions and those running under special conditions offering also nanopositioners.

“Normal” SPMs and Accessories [Runge 2014a]	**Nanopositioners or/and Special Condition SPMs (Environment, Magnetic State of Substrate), Accessories & Components**	
Agilent Technologies	Mad City Labs, Inc. (founded in 1999);	Mad City Labs manufactures nanopositioning systems suitable for super-resolution microscopy, metrology, imaging, interferometry and astronomy. Nanopositioners feature picometer precision, high stability, sensors, closed loop control, imaging and automation software compatibility. Featured products: SPM kit closed loop AFM/SNOM, value priced microscopy instrumentation, multi-axis nanopositioning systems, Nano-MET series
Asylum Research, an Oxford Instruments Company	nPoint, Inc. (founded 1997 as PIEZOMAX Technologies) 49 employees (Facility area (sq. ft): 8,000) [Photonics] which is 743 sq. meters and to be compared with1,900 m^2 for WITec. Attocube had ca. 200 sq. meters with 7 employees in 2004 Buyer’s Guide claim: “All listings are verified annually and updates are made daily”	nPoint designs and manufactures nanopositioning tools for OEM and research applications. Nanopositioning systems provide closed-loop translation in the X, XY, XYZ axes of motion and tip/tilt. Enables high-speed, high-resolution, sub-nanometer precision for optics, semiconductor, defense, aerospace and bio industries. Products include piezo actuated flexure stages and digital control electronics. There are standard products consisting of upgrade kits for AFM and stand-alone research instruments, a growing list of OEM applications and custom design for unique research application. nPoint acts also as a nanopositioning solution provider.

Table 6, continued.

attocube systems AG	Nanomagnetics Instruments Ltd. Established in Oxford, UK, in 1998 to develop Scanning Hall Probe Microscopes (SHPMs) used to map the 3D surface magnetic fields of the specimen simultaneously at nanometer scale.	According to its Web site: After the first product, Room Temperature Scanning Hall Probe Microscope (RT-SHPM), it launched a Low Temperature Scanning Hall Probe Microscope (LT-SHPM/SPM) in 2001. In 2005 it launched its Low Temperature Magnetic/Atomic Force Microscope (LT-MFM/AFM). Products for low temperature down to 20 mK are available. In 2008 Nanomagnetics introduced a High Resolution Ambient MFM/AFM achieving sub-10 nm magnetic resolution in air. It introduced the AQUA nc-AFM in July 2010, claimed to be the first commercial non-contact Atomic Force Microscope in the world, Offerings include related nano-positioners.
Bruker Corporation (Bruker Nano Surfaces)	Cryo Industries of America, Inc. (established in 1984); LaserFocusWorld (Online Buyer's Guide) reports the firm to have 25 employees (year unknown)	It is (was?) a strategic cooperation partner of attocube. CRYO is a supplier of cryogenic systems – standard or custom, open or closed cycle, continuous flow or reservoir type; for various research and industrial applications. Web: "Cryo Industries manufactures "performance by design" cryogenic systems that are guaranteed dependable so you won't have to compromise."
{JPK Instruments} a)		
Nanonics Imaging Ltd (incorporated in 1997)	→	Claims to have recently developed a low temperature SPM system [Runge 2014a]
Nanosurf AG	{Physik Instrumente – PI} PI was founded in 1970 and in 2011 had revenue of ca. €95 million and ca. 680 employees [Physik Instrumente]	According to its Web sites PI is the world's leading provider of nano-positioning products and systems. All key technologies are developed, manufactured and qualified in-house by PI: Piezo components, actuators and motors, magnetic drives, guiding systems, nanometrology sensors, electronic amplifiers, digital controllers and software.

Table 6, continued

NT-MDT Co.	{piezosystem jena GmbH} (founded in 1991 by Dr. Bernt Götz und Thomas Martin of the Friedrich-Schiller-University in Jena; revenue in 2012 was ca. €5 million with ca. 40 employees)	piezosystem jena is a worldwide supplier of high precision piezo positioning equipment. The piezoelectric ceramic based actuating systems and piezo stages are mainly used for the micro and nanopositioning for highly accurate movement of optical devices and optical components. Applications include confocal and ultra-high resolution microscopy, AFM technology, spectroscopy, single photon stimulation, probe alignment and tracking
Park Systems, Inc.	Carl Zeiss MicroImaging GmbH}	Carl Zeiss MicroImaging GmbH is a 100% subsidiary of Carl Zeiss AG. Carl Zeiss MicroImaging is a manufacturer of microscope systems and offers total solutions for biomedical research, the healthcare sector and high-tech industries. The product line spans a broad spectrum from light microscopes and systems for laser scanning microscopy and spectrometry to hardware and software for image processing and documentation.
WITec Instruments GmbH		

a) Not in the US APS (American Physical Society) list.

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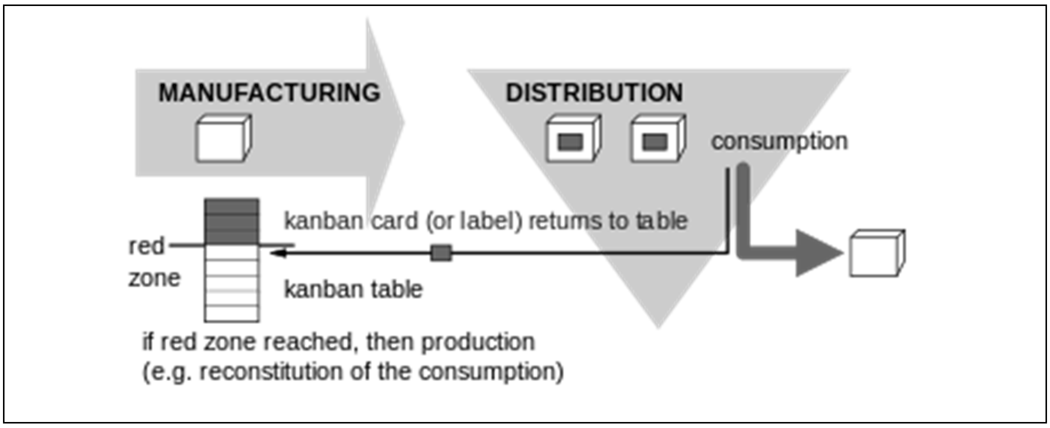
Notes

1. *Piezoelectricity* (the piezoelectric effect) is the ability of *certain materials* to generate an AC (alternating current) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both. The most common piezoelectric material is quartz. Certain ceramics, Rochelle salts, and various other solids also exhibit this effect.
The piezoelectric effect is *reversible*, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied).
The industrial breakthrough came with "Piezoelectric Ceramics", when scientists discovered that barium titanate adopts piezoelectric characteristics on a useful scale when an electric field is applied.
As very high voltages correspond to only tiny changes in the width of the crystal, this crystal width can be manipulated with better-than-micrometer precision, making piezo-crystals an important tool for positioning objects with extreme accuracy, making them perfect for use in motors for positioning.
From http://en.wikipedia.org/wiki/Piezoelectricity,
http://www.explainthatstuff.com/piezoelectricity.html,
https://www.princeton.edu/~achaney/tmve/wiki100k/docs/Piezoelectricity.html.

2. Marcel Thomas: *Flexures*:
http://web.mit.edu/mact/www/Blog/Flexures/FlexureIndex.html (last access 8/23/2014).
Flexures allow engineers to provide motion in desired directions, but constraint in other directions. Flexures are important for engineers because they allow stiction-less (stiction – Haftreibung), controlled, limited-range motion.
There are topologies of all of the flexures. "The first step in flexure design is to identify the degrees of freedom. These are the desired directions of travel. Conversely, you could find the desired constraints first. That is, it may be easiest to identify which directions are undesirable for travel. Every rigid body has six degrees of freedom: three for translation and three for rotation. Keep in mind that the flexures that you design will not be infinitely stiff in the constraint directions, but if designed properly will be orders of magnitude stiffer than the degrees of freedom."

3. *Kanban*. http://en.wikipedia.org/wiki/Kanban.
Kanban (literally signboard or billboard in Japanese) is a scheduling system for lean and just-in-time (JIT) production. Kanban *is a system to control the logistical chain from a production point of view*, and is not an inventory control system.

Kanban became an effective tool in support of running a production system as a whole and it proved to be an excellent way for promoting improvement. Problem areas were highlighted by reducing the number of kanban in circulation. One of the main benefits of Kanban is to establish an upper limit to the work in progress inventory, avoiding overloading of the manufacturing system.
One key indicator of the success of production scheduling based on demand "pushing" is the ability of the demand-forecast to create such a "push."



4. *Quantum Dot*: http://www.sciencedaily.com/articles/q/quantum_dot.htm, http://en.wikipedia.org/wiki/Quantum_dot.
A quantum dot is a *semiconductor nanostructure* that confines the motion of conduction band electrons, valence band holes, or excitons (bound pairs of conduction band electrons and valence band holes) in all three spatial directions. The confinement can be due to electrostatic potentials (generated by external electrodes, doping, strain, impurities) or the presence of an interface between different semiconductor materials (e.g. in core-shell nanocrystal systems)
A quantum dot contains a small finite number (of the order of 1-100) of conduction band electrons and valence band holes (excitons), i.e., a finite number of elementary electric charges. Small quantum dots, such as colloidal semiconductor nanocrystals, can be as small as 2 to 10 nanometers, corresponding to 10 to 50 atoms in diameter and a total of 100 to 100,000 atoms within the quantum dot volume. Self-assembled quantum dots are typically between 10 and 50 nm in size.
Quantum dots are particularly *significant for optical applications* due to their high extinction coefficient.

5. *Oxford Instruments acquires VeriCold Technologies GmbH*, http://www.zenopa.com/news/18252517/Oxford_Instruments_acquires_VeriCold_Technologies_GmbH (last access 1/4/2014);
VeriCold Technologies sold to Oxford Instruments, http://www.ewh.ieee.org/tc/csc/europe/europeguide/VericoldTechnologies.html (last access 1/4/2014).

6. *Qubit or Quantum Bit:* http://en.wikipedia.org/wiki/Qubit.
A qubit is a two-state quantum-mechanical system, such as the polarization of a single photon: here the two states are vertical polarization and horizontal polarization. Quantum mechanics allows the qubit to be in a superposition of both states at the same time, a property which is fundamental to quantum computing.

7. *attocube Research Award:* http://www.cens.de/research/attocube-research-award/**.**

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