Table of Contents

Introduction to the 2011 annual report

FIRST – Frontiers in Research: Space and Time – is a world-class nanotechnology laboratory dedicated to the needs of the research community from ETH Zurich. By pooling together resources and know-how, it provides to the scientists access to top-notch equipment and techniques. Besides its importance as a user's lab, FIRST has also a fundamental role to maintain a technical know-how and teach PhD students and Post-Docs the latest fabrication technologies. In FIRST, users are intervening at all levels: the most experienced perform key interventions in the maintenance and in the choice of the new equipment, as well as act as mentors to the beginners.

The whole operation of FIRST is driven by the FIRST operation team (FOT) and FIRST technical team (FTT). They must balance the challenging requirements set by the necessity to keep a high level of safety, maintain a high level of technical expertise in a user staff with a large turn-over as well as keep a high availability of the equipment in face of the natural instrument wear and tear.

2011 has seen a continuation of the trend of the past years with a further increase in the number of users and groups benefitting from FIRST. This platform continues to play a major role in a whole domain of scientific research performed in ETH. The auspicious beginnings of the SNF-supported centers of excellence in D-PHYS, e.g. on quantum science and technology (QSIT), will undoubtedly continue to generate strong scientific programs in FIRST. At the same time, FIRST remains an important attractive feature of ETH, playing an important role as an attractor for new academic staff.

On the human side, the last year has witnessed a significant change of guard, as Dr. Otte Homan has decided to pursue a new carrier in Australia. In the name of all FMT members, I would like to thank Dr. Otte Homan for his hard work, dedication and kindness, used to bring FIRST forward, starting from its design all the way to its 10 years of existence. His successor, Dr. Yargo Bonetti, will start officially in March.

The start of the new Plassys evaporator, as well as the new SEM, helped to keep a short turnaround time for processing despite the large number of users. During this year, through the support of the school, a new profiler was bought and installed, replacing an aging and problem-prone instrument.

The success of FIRST can be measured by the very high scientific output as witnessed by the numerous scientific publications generated, or by the number of highly qualified PhD students and post-docs that have learned the latest techniques in nanotechnology it produces. To me, however, its best achievement is as real but more difficult to quantify: its ability to foster a true spirit of collaboration and emulation between young researchers from different disciplines. In my interactions with students as well as with prospective academic hires, I can see how much these aspects are important for the future of our institution.

Jerome Faist

FIRST – Frontiers in Research: Space and Time

The FIRST Center for Micro- and Nanoscience of ETH Zurich is a centralized technology platform that serves a broad range of users with its cleanroom infrastructure in the field of semiconductor micro- and nanotechnology. FIRST lab offers state-of-the-art equipment for bottom-up and top-down technologies. FIRST is a user lab. Main objectives are the technical training of the lab users on the machines, teaching basic technologies and maintaining equipment and infrastructure. In 2011, FIRST trained more than 270 individual users on all levels from semester, master/diploma students to PhD students and Post-Docs. The fields of the projects based in FIRST are manifold and cover nearly the full range of ETH departments: physics, chemistry, electrical and mechanical engineering, materials science, environmental engineering, food sciences and biology (Figure 1).

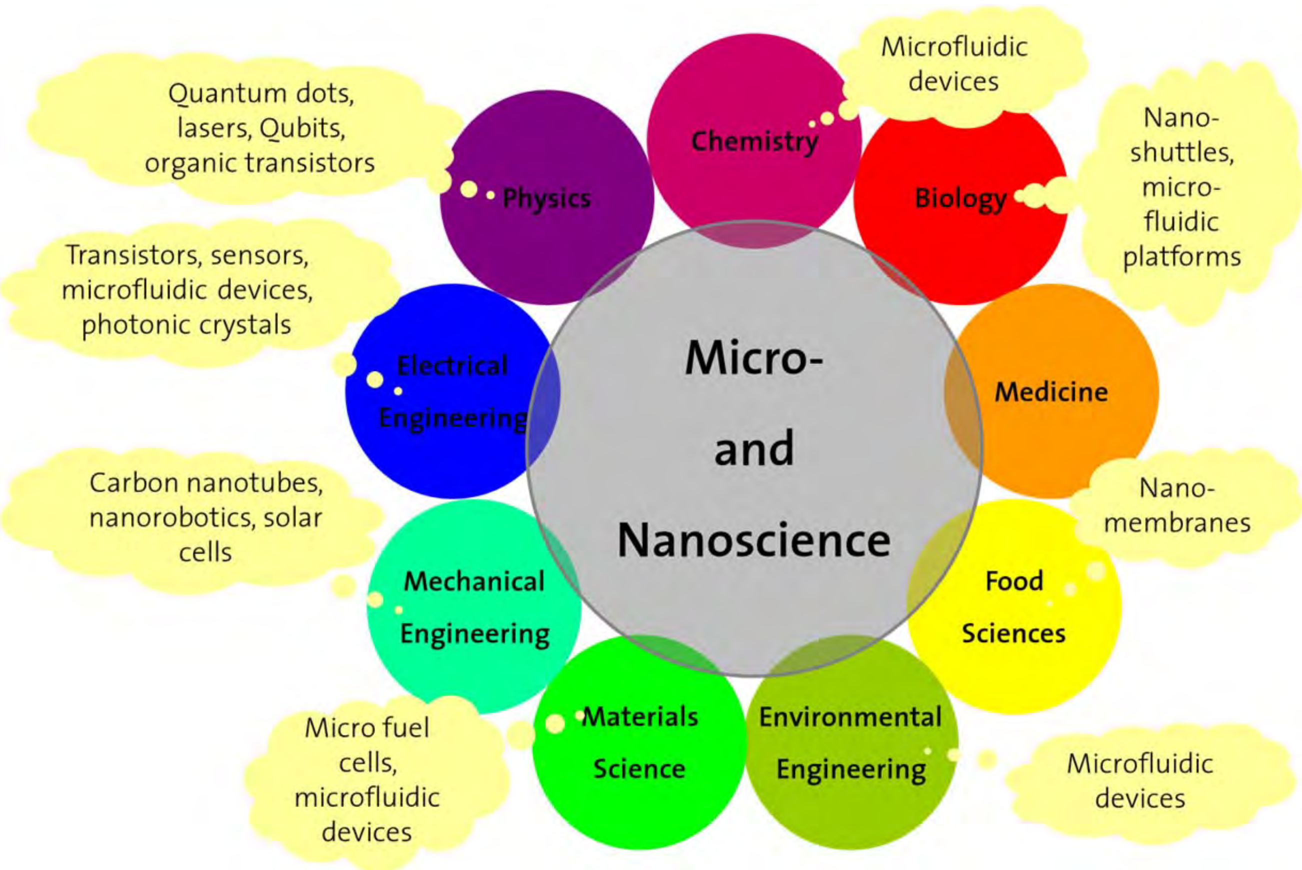
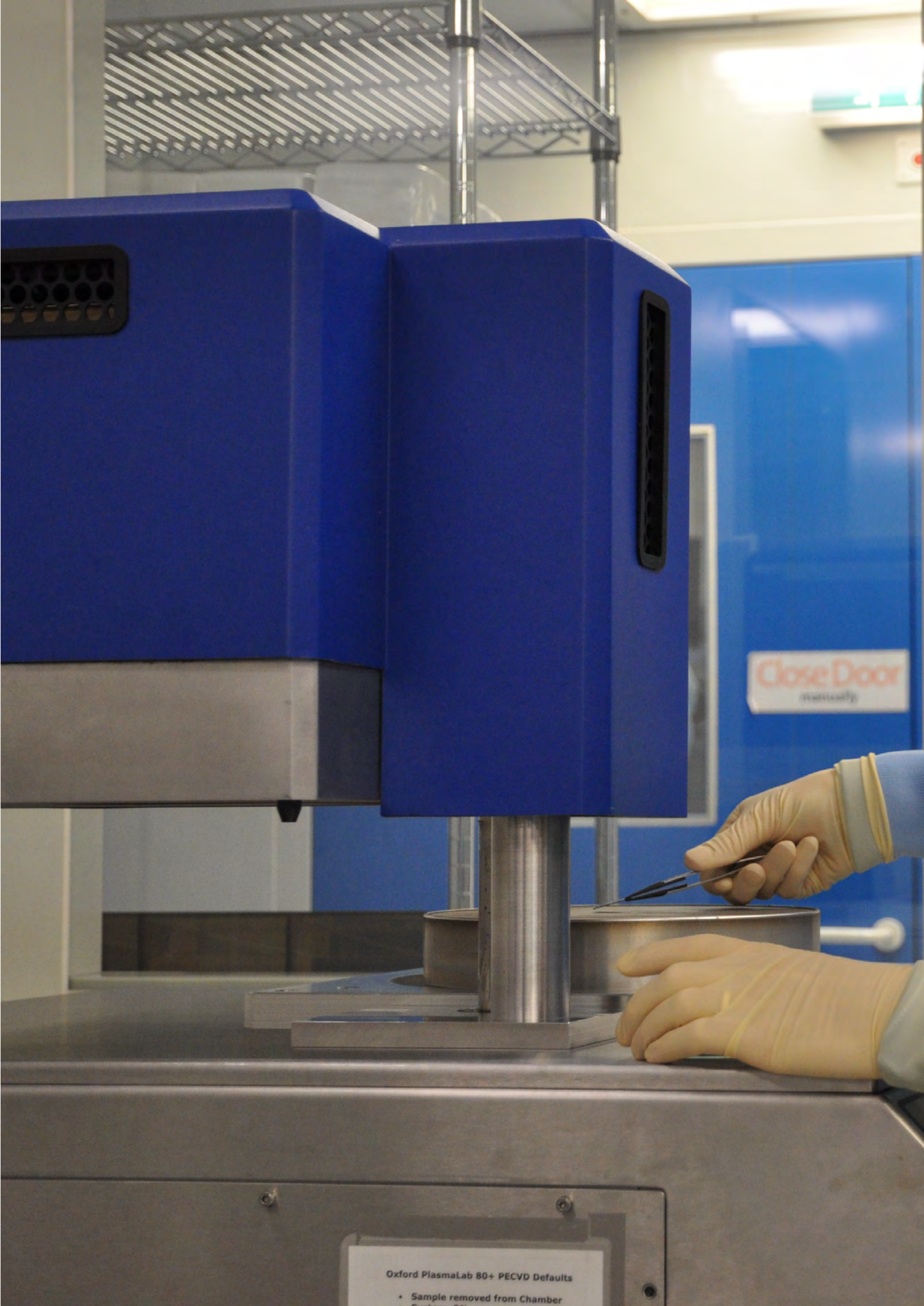


Figure 1:
Departments using the cleanroom infrastructure of FIRST Center for Micro- and Nanosciences and a selection of their research fields.


Close Door
Oxford PlasmaLab 80+ PECVD Defaults
• Sample removed from Chamber


21.6
48.2
14

Organisation of FIRST

FIRST Lab is directly supported by the Executive Board of ETH Zurich under the lead of the Vice President of Research and Corporate Relations and chaired by the FIRST coordinator (Figure 2). Long-term scientific and technical orientation of FIRST is determined by the FIRST Management Team (FMT). FIRST is operated by the FIRST Operation Team (FOT) with the assistance of the FIRST Technical Team (FTT) and by the support of FIRST users (FMT staff).

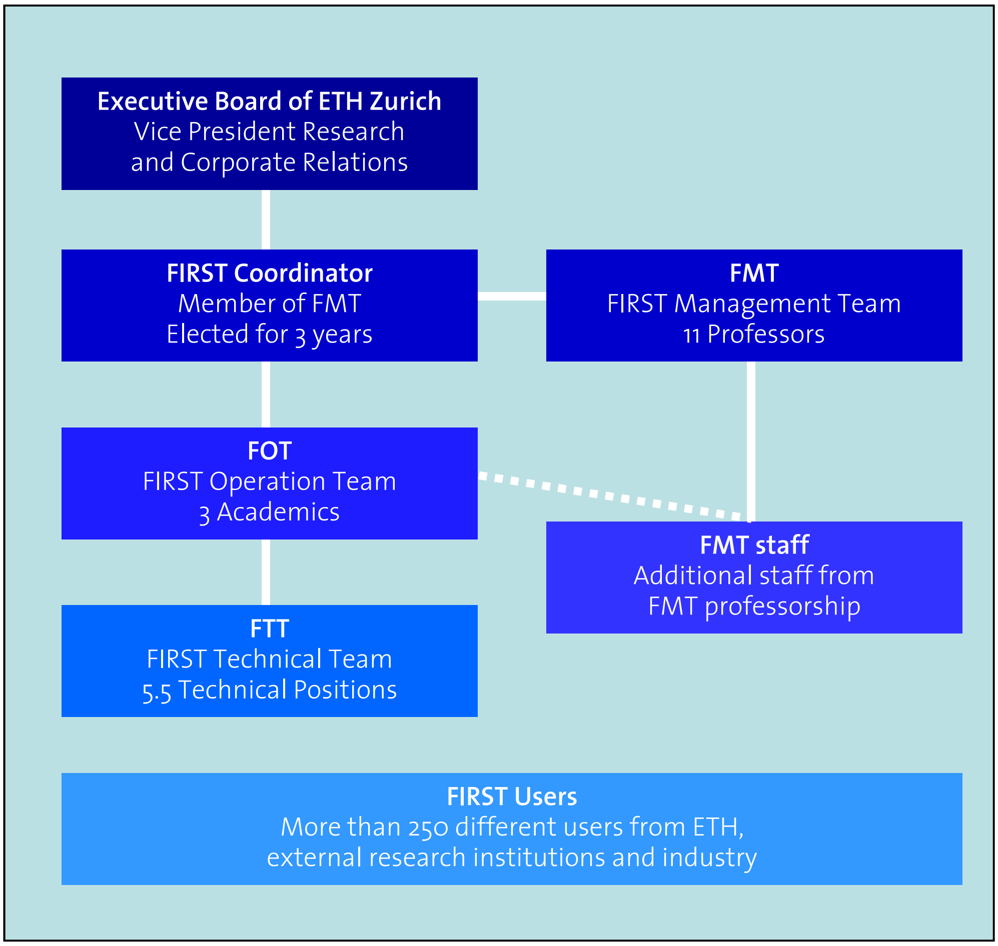


Figure 2:
Organization of FIRST

The FIRST-Management Team determines the scientific and strategic directions of FIRST. It consists of those ETH professors who have a major technological and scientific involvement and take a responsibility in FIRST by contributing actively to the operation of the FIRST technology lab. A list of FMT members is given below.

Each FMT professor has to contribute manpower to the FIRST lab to support its operation. This personnel support is referred to as the FMT staff. FMT staff contributions are provides by training lab users and servicing equipment as equipment responsible person, mentoring new

lab users or by supporting the procurement of new equipment. The FMT professors and their group members are considered to be primary users of the FIRST lab.
The FIRST coordinator represents the FMT to the ETH management. He reports to the Vice President Research and Corporate Relations and represents the FMT and the FOT. The FIRST coordinator is elected for a 3-years period by the members of the FMT and appointed by the ETH Board. The FIRST coordinator is a member of the FMT.

The FMT in 2011:

Prof. Dr. C. Bolognesi
Terahertz Electronics Group
http://www.mwe.ee.ethz.ch/

Prof. Dr. J. Dual
Mechanics and Experimental Dynamics
http://www.zfm.ethz.ch

Prof. Dr. K. Ensslin
FIRST coordinator 2004–2007
Nanophysics;
http://www.nanophys.ethz.ch

Prof. Dr. J. Faist
FIRST coordinator 2010–2012
Quantum Optoelectronics Group
http://www.qoe.ethz.ch

Prof. Dr. C. Hierold
FIRST coordinator 2007–2009
Micro- and Nanosystems
http://www.micro.mavt.ethz.ch

Prof. Dr. A. Imamoglu
Quantum Photonics
http://www.quantumphotonics.ethz.ch

Prof. Dr. H. Jäckel
FIRST coordinator 2002–2003
High-Speed Electronics and Photonics
http://www.ife.ee.ethz.ch

Prof. Dr. U. Keller
Ultrafast Laser Physics
http://www.ulp.ethz.ch

Prof. Dr. B. Nelson
Institute of Robotics and Intelligent Systems
http://www.iris.ethz.ch

Prof. Dr. R. Spolenak
Nanometallurgy
http://www.met.mat.ethz.ch

Prof. Dr. A. Wallraff
Quantum Device Lab
http://www.qudev.ethz.ch

FIRST Operation

The daily business of FIRST is managed by a team of three scientists (FIRST Operation Team, FOT) with the support of technicians (FIRST Technical Team, FTT). The FIRST Technical Team consists of 5.6 full positions shared by 6 technicians, 1 team assistant and 1 person for IT support. The main fields of operating FIRST lab are education and training, facility management, scientific project support and equipment services (Figure 3).

FIRST is a user lab. Doctoral, master and semester students as well as Post Docs and technicians can use the equipment. Operating the equipment and basic processes will be taught by the FIRST staff and experienced lab users. It is in the responsibility of the FOT to ensure compatibility of processes and the access to the equipment, to manage and carry out teaching and training, to service the state-of-the-art infrastructure and to manage the technical infrastructure of the cleanroom.

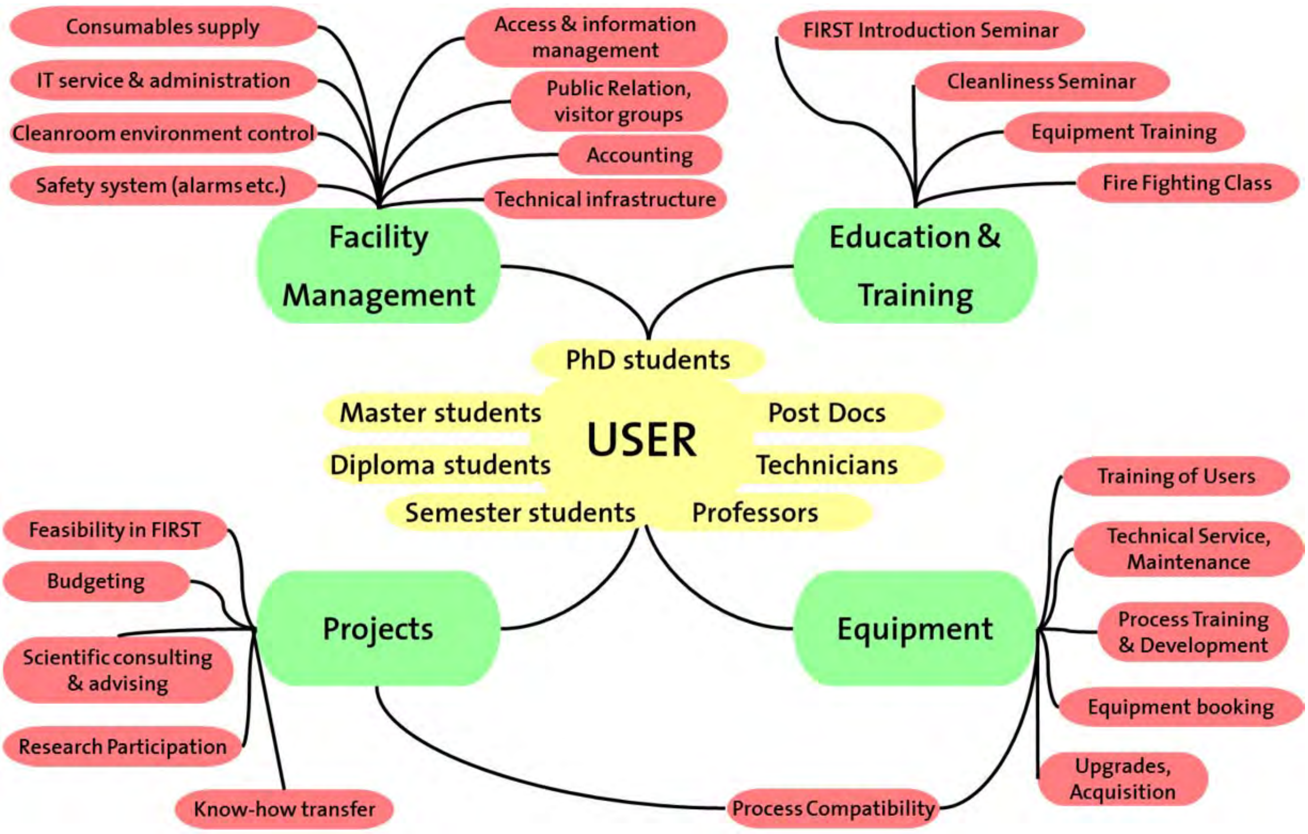


Figure 3:
Operation fields of the FIRST staff.

FIRST is open to all users from inside and outside ETH Zurich. However, the focus of FIRST is on teaching and training to provide hands-on experience to the single user. A general process service or technical developments are not offered.

FIRST is operated from 7 am to 7 pm on regular work days. Outside regular working hours (e.g. during nights, weekends and public holidays) special restrictions apply with respect to the use of chemicals and dangerous processes. Night work rules apply.

In 2011, the FIRST staff took leave of two colleagues: Dr. Otte Homan who had been working with us for 10 years and Dominique Aeschbacher who joined the team 5 years ago. We thank both former team members for their work and we wish them all the best in their new jobs.

Figure 4:
The FIRST staff in June 2011. From left to right: Dr. Otte Homan, Martin Ebnöther, Christian Fausch, Dr. Emilio Gini, Maria Leibinger, Sandro Bellini (below), Hansjakob Rusterholz, Dr. Silke Schön, Tracy Napitupulu, Petra Burkard.

Prof. Dr. Jérôme Faist

FIRST Coordinator

2010 - 2012

Dr. Otte Homan

FIRST Operation Team

Thin film technology
Processing &lithography
Safety & health

Dr. Emilio Gini

FIRST Operation Team

MOVPE, characterization
Infrastructure
Finances

Dr. Silke Schön

FIRST Operation Team

MBE, characterization
User interface & projects
Public relations

Dominique Aeschbacher (50%)
FIRST Technical Team

Computer administration

Christian Fausch (50%)

FIRST Technical Team

Electronics,
semiconductor
characterization

Sandro Bellini

FIRST Technical Team

Wet chemistry
E-beam lithography

Maria Leibinger (50%)

FIRST Technical Team

Photolithography
E-beam lithography
CV profiling

Petra Burkard (50%)

FIRST Technical Team

Thin film technology
Plasma technology

Hansjakob Rusterholz

FIRST Technical Team

MBE support
Wire bonding
Web / Graphics

Martin Ebnöther

FIRST Technical Team

MOVPE support
Laboratory supplies

Tracy Napitupulu (50%)

FIRST Technical Team

Team assistant
User administration


ANALYZER
PINHOLE
POLARIZER

FIRST equipment: general overview

FIRST offers more than 60 pieces of equipment to its users. The equipment pool ranges from epitaxial growth techniques for bottom-up nanofabrication over material characterization and inspection methods to a large variety of processing equipment for top-down nanofabrication and back-end processing. Main focus is on III-V semiconductor fabrication and processing. However, other processes can be carried out after consulting the FIRST operation team for compatibility and availability.

Each piece of equipment in FIRST is taken care of by two responsible persons. They are either FIRST staff members or experienced users. The equipment responsible persons set the rules of use and reservation, organizes and/or carries out the maintenance, trains the user on the equipment, and supports the know-how transfer among the users. About 60 different persons are responsible for one or more pieces of equipment in FIRST.

The use of each piece of equipment in FIRST requires an on-site training. The equipment responsible person teaches the new user the technical operation and scientific background of the technique. Equipment training is mandatory to each user and staff member independently of any level of experience. It will guarantee that the particular equipment is operated with care, that customized technical adaptions specific to the equipment are understood, that the user is able to successfully and safely carry out his or her processes, and that the equipment is left in the default state after use to allow for the next user to start without problems. Training times depend on the complexity of the equipment. A short manual is provided with each piece of equipment to allow each user to start operation of the equipment independently. An online reservation system is provided to book the equipment in advance. To avoid bottleneck reservation rules depend on the equipment and will be taught during the equipment training.

A detailed description of the equipment pool is provided in this chapter. Key figures for each piece of equipment together with the contact data of the responsible persons can also be found on the webpage of FIRST (http://www.first.ethz.ch/infrastructure/equipment).

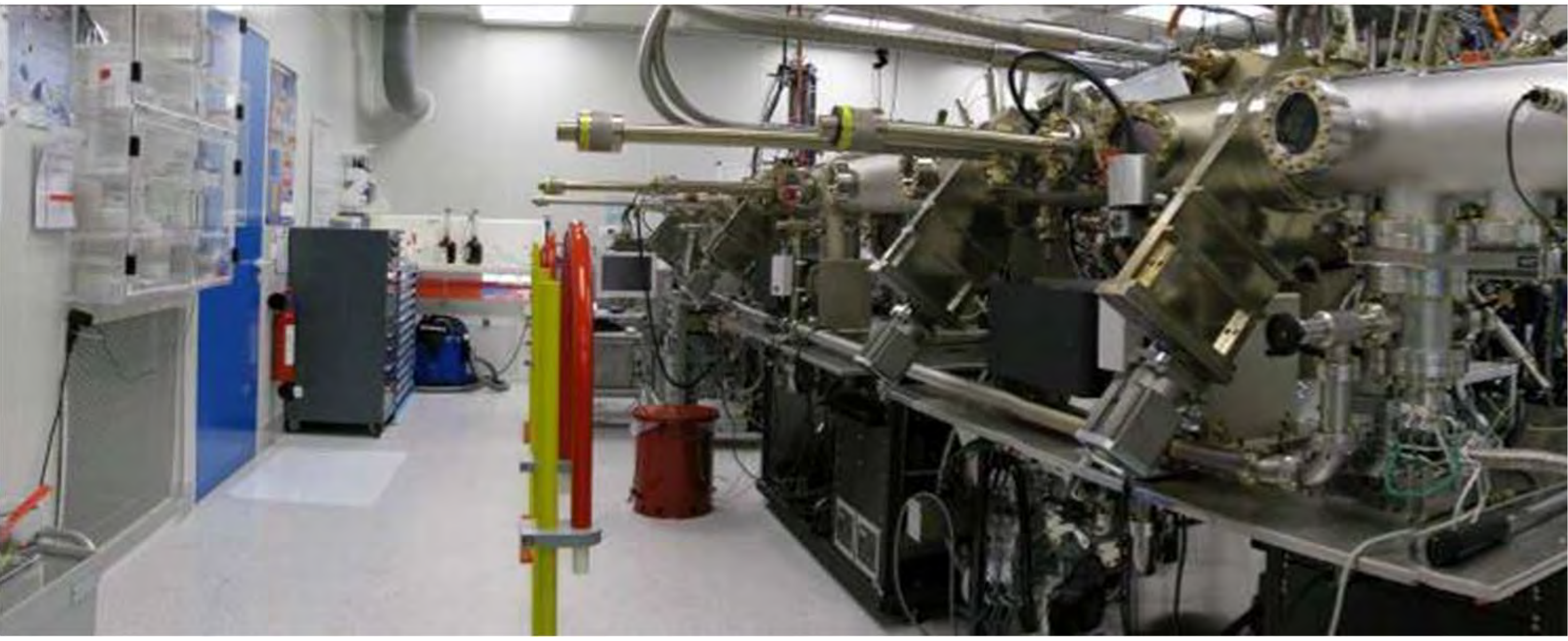


Figure 5:
MBE systems in FIRST: 2 Veeco GEN III systems (left page) and a VG V80H system (right page).

Molecular beam epitaxy (2 Veeco/Applied EPI Gen-III MBE systems, 1 VG V80H MBE system)

- **Objective:** Epitaxial growth of phosphides, arsenides, antimonides and dilute nitrides on up to 4-inch substrates with Si-, C- or Be-doping for active and passive semiconductor devices, e.g. quantum cascade lasers, surface emitting lasers, optical switches, saturable absorbers, and for quantum dot growth and nanocoil fabrication.
- Three growth chambers are available with band edge detection (BandiT, DRS), pyrometers, reflectometry (Laytec EpiR) and reflection high-energy electron diffraction (RHEED) for in-situ growth monitoring and residual gas analyzer (RGA, Stanford systems). The two Veeco MBE systems are connected to each other and to the preparation chamber by buffer chambers. Two introduction chambers one on each side of the transfer tunnel allow for convenient sample loading.
- Chamber 1 (**As MBE**, Gen III) is dedicated to the growth of arsenides only. The system is equipped with two gallium cells, two aluminum cells, indium and silicon doping cells. P-doping is achieved with a CBr_4 source (Riber). An arsenic valved cracker (mark IV, Veeco) supplies As_4 or As_2 molecules. The pumping system consists of a cryogenic pump and an ion pump. Only GaAs substrates are allowed to be used in the system to avoid cross contaminations and to guarantee a low background concentration required by the currently running projects.

- Chamber 2 (**P MBE**, Gen III) is dedicated to the exploratory material growth. The system is equipped with two gallium cells, two aluminum cells, indium and silicon doping cells. An arsenic valved cracker (mark IV, Veeco) supplies As_4 or As_2 molecules. In addition, a phosphorus valved cracker (Veeco) and an antimony valved cracker as well as a nitrogen plasma source (Unibulb, Veeco) are available. The pumping system consists of turbo and ion pumps. A recovery chamber attached to the system allows for the recovery of white phosphorus before maintenance. Different substrate materials can be used in the P MBE system: GaAs, InP, GaSb, InAs.
- Chamber 3 (**VG MBE**, V80H) is dedicated to the growth of arsenides only. Aluminum, gallium, indium and silicon doping cells are available. An arsenic valved cracker (mark IV, Veeco) supplies As_4 or As_2 molecules. The pumping system consists of a cryogenic pump and an ion pump. GaAs and InP substrates can be used in the VG MBE.
- An additional **preparation chamber** is equipped with an atomic hydrogen source for surface oxide reduction processes before epitaxial regrowth and RHEED system.

In 2011, 10 MBE growers from five different ETH groups and FIRST used the three FIRST MBE systems. The weekly MBE meeting provides the platform for experience exchange and organization of the machine usage. A well-maintained database summarizes growth run parameters and maintenance issues. A large MBE wiki knowledge base supports the know-how transfer and provides technical and best-practice information.

Metal-organic vapor phase epitaxy (AIX 200/4)

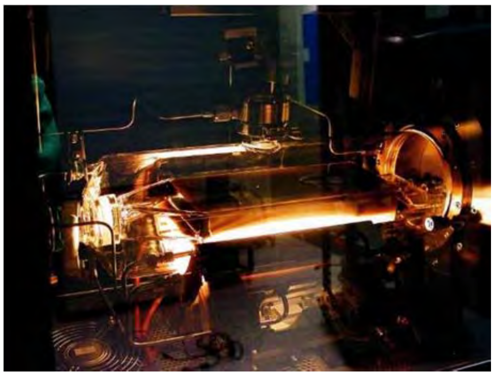


Figure 6:
MOVPE reactor.

- Growth of phosphides, arsenides and antimonides on InP and GaAs substrates with zinc carbon for p-type, silicon or sulfur for n-type doping and iron for semi-insulating material (Figure 6).
- Growth of nanowhiskers.
- EpiRAS in-situ growth monitoring.

Thin film deposition and annealing

- Plasmalab 80+D plasma deposition (**PECVD**) of SiN_x and SiO_x films (Oxford Instruments).
- Three **electron beam evaporation systems** for metals, superconductors and dielectric materials (Leybold, Plassys). In 2010 a new Plassys MEB550SL system (8 pocket 10kV 10kW electron beam system with ion beam cleaning) was purchased and is now in operation.
- DC/RF **magnetron sputter deposition** system for metals and dielectric films (PVD Products).
- **Rapid thermal annealing system** with N2 and N_2/H_2 gas supply (JIPELEC).

Materials characterization

- Two 4-crystal, high resolution, **X-ray diffraction systems** (Seifert 3003 PTS-HR, Figure 7, and Philips X'pert).
- **Two digital scanning electron microscopes** (Zeiss).
- **C-V doping profiler** (Dage).
- **Hall-effect measurement system** Accent HL5500.
- **Stylus force step profiler** (Alphastep 500).
- **Atomic force microscope** (MFP-3D,

Figure 7:
Seifert X-ray diffraction system.

Asylum Research).

- **Optical microscopes** (Nikon Eclipse L200 and L200D).

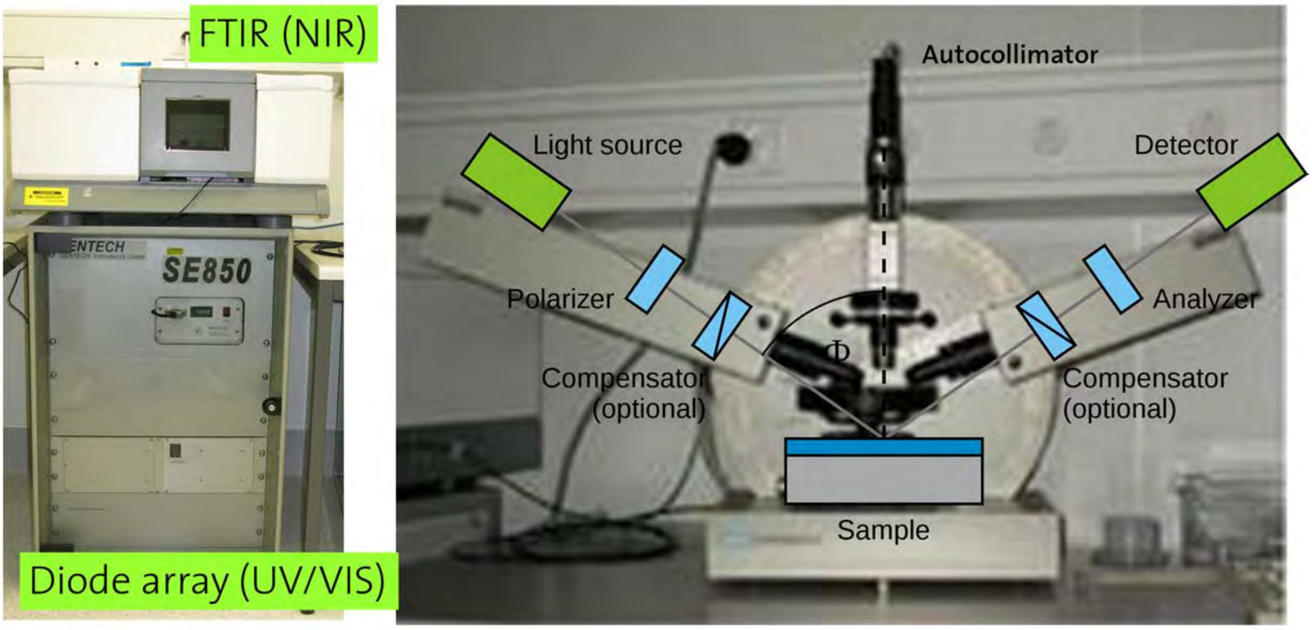


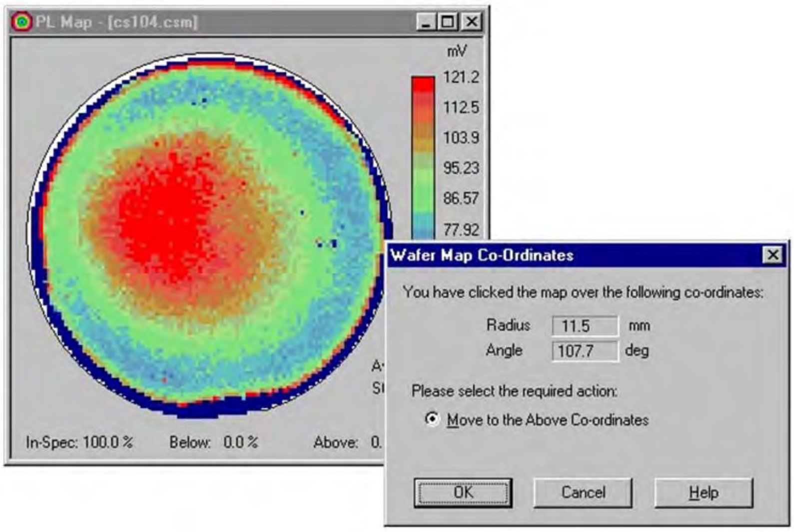
Figure 8:
Spectroscopic ellipsometer Sentech SE 850.

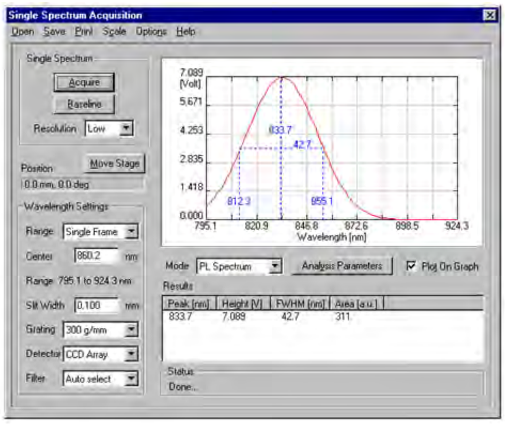
- **Spectroscopic ellipsometer** (Sentech SE850, Figure 8):
  This white-light ellipsometer covers the wavelength range from 350 nm to 1700 nm. The light source is a Xe lamp. As detector serve a diode array for the UV/VIS range and an FTIR for the NIR range. The micro-focus option provides a spot size of several hundred micrometers in diameter in order to measure laterally inhomogeneous samples. The sample is measured in horizontal position and adjusted with the help of an autocollimator. The software Spectraray acquires the values of the wavelength-dependent ellipsometry angles $\Psi(\lambda)$ and $\Delta(\lambda)$. A model of the sample structure can be built based on the refractive indices of the single layers. This model can be fitted and the refractive indices and the thickness can be obtained. A variety of optical functions is available: Sellmeier function, Cauchy function, Drude model, Tauc-Lorenz model etc. Graded layers can be simulated by the effective medium approach.

- **Rapid photoluminescence mapping system** (Accent RPM 2000, Figure 9):
  The photoluminescence mapper (PLM) is equipped with two lasers (532 nm & 785 nm) and a white light source, a 300-nm monochromators and three different gratings (150 g/mm, 300 g/mm and 600 g/mm). A CCD camera and an InGaAs integrated array

detect the photoluminescence in the VIS and NIR wavelength range, respectively. Line spectra of intensity versus wavelength as well as full maps can be measured.

Figure 9:
Rapid photoluminescence mapping system Accent RPM 2000 (left picture).
Integrated photoluminescence map of a semiconductor wafer (picture bottom left). The map coordinates can be easily accessed to read out the local PL intensity.
Spectral photoluminescence scan of a semiconductor sample (picture bottom right).





Optical lithography

- Karl Süss **MJB3** manual contact printing **mask aligner**, also suited for IR back-side alignment. It uses 365 nm and 405 nm UV-light. Optical resolution is approximately 0.4 µm.
- Karl Süss **MA6** semi-automatic contact printing **mask aligner** with split field optics. Currently configured for 2/3/4-inch substrates and 3/4/5-inch masks. It uses 365 nm and 405 nm wide-band UV-light. Optical resolution is approximately 0.4 µm.
- ABM Inc. deep **UV** contact printing **mask aligner**, configured for either 220/258 or 365/405 wavelength exposures. Chucks and mask holders for small (5x5mm^2) chips and wafers (2”, 3”, 4”) are available. The optical resolution in PMMA and other deep UV sensitive resists is below 300 nm.
- New **photoresist spinners**, furnaces and hot plates (see above), wet processing area.

Electron beam lithography

Two electron beam lithography systems (**Raith150 and Raith150TWO**), dedicated control software environment. Thermal Schottky field emitter source with 2 nm beam resolution, and with variable beam energy between 0.2 keV and 30 keV, with beam currents between 15 pA and 3.8 nA. Maximum sample size is 4 inch on the Raith150 and 6 inch on the Raith150TWO. Write field stitching and overlay accuracy are better than 40 nm for 200 μm write field size. The Raith150TWO system also offers wafer height measurement and control, as well as a fixed-beam moving-stage exposure option for very long structures. It has a new 20 MHz pattern generator, equipped with very efficient data object fracturing algorithms. The current state-of-our-art is sub-10nm quantum structures.

Atomic force microscope lithography

Atomic force tip oxidation of Ti, GaAs and graphene films, using a scanning force microscope in atmospheric conditions. Write fields are approx. 10 μm x 10 μm, and sub-micron to nm line width has been demonstrated.

Wet and dry etching

- $20 m^2$ **wet benches** with ultrasonic baths, spin-dryer, heater/ chiller, solvents, acids, base liquid handling.
- 2x **RIE** systems (Oxford PlasmaLab 80) with fluorine based chemistry for dielectrics and metals (Figure 10).
- **ICP** system (Oxford PlasmaLab 180): Chlorine based chemistry, 13.56 MHz RIE and synchronous ICP power sources, load lock.

Figure 10:
Reactive ion etching (RIE).

- Technics Plasma 100E down-stream microwave **oxygen asher**.
- **UVOCS** ultra violet ozone cleaning system.

LPCVD nanotube and nanowire deposition

Figure 11:
Low-pressure chemical vapor deposition (LPCVD).

Carbon nanotube and silicon nanowire research is boosted by our LPCVD system from ATV Technology (Figure 11). It allows catalytic growth of single- and multi-walled carbon nanotubes (CNTs) from methane gas, as well as silicon nanowires (SiNWs) from silane gas on structured substrates (e.g. MEMS and NEMS devices) at low process pressures. If desired, low frequency plasmas can be generated by dipole antennas inside the reactor. Novel built-in micro-heaters allow localized CNT deposition on individually heated areas on substrates.

Atomic layer deposition

MEMS and NEMS processes, as well as basic chemistry research, profit from the atomic layer deposition system from Picosun (Figure 12). It is configured for the controlled and defect free deposition of Al_2O_3 and ZnO_2 from metal-organic precursors and pure water, one atomic layer at a time. In 2010, a second heated source for solid and low pressure liquid precursors and a special receptor for powder coating applications were purchased, installed and tested, allowing HfO_2, TiO_2 and powder coatings.

Figure 12:
Atomic layer deposition (ALD).

Back-end-of-line processing

- **Lapper** PM5 (Logitech)
- **Electroplating** facility
- **Wafer saw** (DISCO)
- **Two wire bonders** (Westbond) for Au and Al
- **Wafer bonder** (AML)


MA6 Reservation List
SUSS MA6 - Short User Manual

Scientific equipment: additions and upgrades in 2011

New stylus force profilometer

Our Tencor Alphastep 500 had increasingly suffered from failures. As no reasonable soft- and hardware upgrades were available, we decided to buy a new system. The winner of the evaluation was the Dektak XTA from Bruker Nano. The stage is fully motorized and steps up to 1000 µm height on a scan length of 55 mm can be measured. The Visions64 software includes stitching capability to extend the scan length up to 200 mm by stitching multiple scans together. With the automated measurement collection feature, line scans and 3D maps in multiple locations can be programmed and analyzed. The system is placed on a pneumatic vibration isolation table in order to take advantage of the high precision of 0.5 nm. Within some weeks more than 60 users were trained on the new system and there feedback is throughout positive.

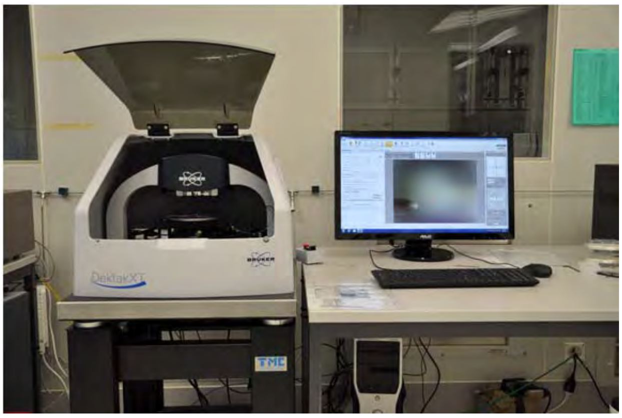


Figure 13:
The new Dektak XTA profilometer in FIRST.

Tencor Stressmeter

For the measurement of wafer curvatures and the determination of build-in stress in wafers FIRST acquired a stressmeter. Curvatures are measured by dual wavelength (670 nm and 780 nm) laser scanning on reflecting surfaces. The chuck size is up to 200 mm. Curvature radii from 2 m up to 30 km can be measured. The system can be heated up to 500 degrees C to measure elastic constants and thermal expansions coefficients.

Figure 14:
New electron Tencor Stressmeter in FIRST.

Langmuir-Blodgett Trough

Langmuir-Blodgett Deposition Troughs are used for the fabrication and characterization of single molecule films. They offer precision control over the lateral packing density of molecules (Langmuir films) and the creation and transfer of such well-ordered functional films to solid surfaces (Langmuir-Blodgett films). The Langmuir-Blodgett Deposition Trough from KSV NIMA enables thin film fabrication at the gas-liquid interface. It is equipped with a dipping well and a dipping mechanism for Langmuir film deposition onto solid substrates at a desired packing density.

A Langmuir film is an insoluble monolayer of functional molecules, nanoparticles, nanowires or microparticles that reside at the gas-liquid or liquid-liquid interface. The monolayer is organized under compression The Langmuir film is transferred to a solid substrate after compression by vertically moving the sample through the monolayer. Nanoscale films of custom thickness can be built up by repeating the deposition (Figure 15).

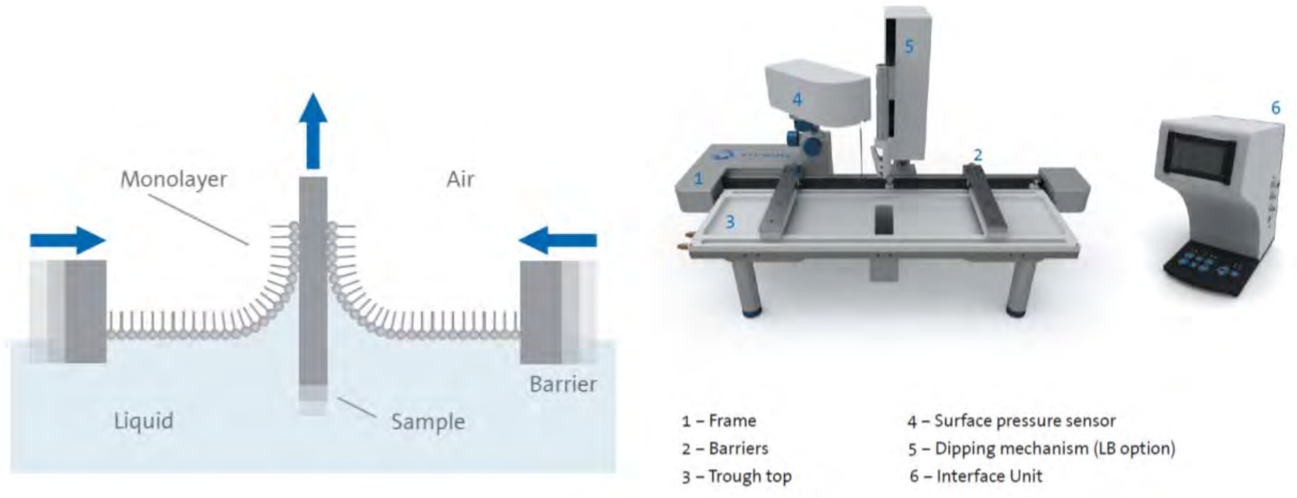


Figure 15:
Schematic drawing of a Langmuir-Blodgett deposition technique (left drawing) and KSV NIMA Langmuir-Blodgett Deposition Trough (right picture).

Improvement of cooling for RIE76

This 17-year old Plasmalab 80 plus dry etching system is used to etch materials like metals that may contaminate the system and to develop new processes with unknown contamination potential. The temperature of the stage used to be controlled by an external heater/chiller in the range from 5 to 35 degrees C. Coming into age it often failed and finally has been removed. The cathode is now kept on a constant temperature of 18°C by its connection to our process cooling water ring.

New cabinets for wet chemistry

The increasing number of FIRST users led to a bottleneck for the storage of the personal processing tools in the wet chemistry room. Many users had to store their utensils in plastic boxes that were piled up in the room. We decided for a new layout of the storage place in the wet chemistry room. At the end of October, the new cabinets were delivered. The new arrangement in wet chemistry room gives us a lot more storage space for all the user groups and the whole equipment which is necessary for pursuing professional processing. Compared to the old situation we increased the storage area by a factor of four. All groups have now sufficient and easily accessible space to store their tools in the vicinity of the wet benches.

Figure 16:
New cabinets in wet chemistry.

Connection of critical systems to our uninterruptible power supply

Several power failures in the past resulted in uncontrolled shutdown of systems with damage of expensive parts. Examples are the Pd-purification cell for hydrogen in the MOVPE, cathodes of electron beam systems or an ion pump. This year, the MOVPE, 2 SEMs and 2 EBLs were connected to the battery buffered system. Due to the higher power consumption the span time has been reduced but still covers 90 minutes. If further systems are connected to our UPS, an expansion of the battery capacity has to be considered.

The VG-MBE system is power buffered by its own UPS. This system has undergone a major upgrade and has got new batteries.

LPCVD upgrades

Low-pressure chemical vapor deposition (LPCVD) is used for carbon nanotube growth and for catalyzed silicon nanowire synthesis. The pressure controller has been repaired which suffered from a memory error. The gas supply of toxic diborane was permanently demounted, as boron is no longer used. After contamination issues which corrupted the growth of nanotubes, a spare reactor inliner was purchased. The quartz inliner arrived ten months after ordering and is stored in-house for immediate replacement.

A major change of the cooling system was initiated. So far, the aluminum chiller plate was cooled directly by the main cooling water cycle (mixture of deionized water and tap water). Heavy corrosion on a visually not accessible aluminum part took place - several millimeters deep. Consequently, the quartz bell of the reactor front door got damaged as quartz pieces broke off and the rubber sealing leaked. Luckily, interlocks blocked heating of the reactor. In case the reactor would have been hot during the first occurrence of the water leak, the generation of steam would have had likely destroyed the whole reactor. Now, the cooling cycle will be switched to a glycol-based coolant with corrosion inhibitors as prescribed by the manufacturer. The corrosion-inhibited glycol will be circulating in a primary cycle only - linked by a heat exchanger to the main cooling system which is still running with pure water. The heat exchanger is less costly and potentially more robust against corrosion than the safety-relevant aluminum chiller plate of the reactor front door.

FIRST technical infrastructure and safety

FIRST's total area of 860 m^2 contains 10 cleanroom cabins with an area of 400 m^2. The air in the cabins is controlled and monitored with respect to particle concentration, temperature and humidity and is exchanged up to once per minute. Various loops with different water qualities are installed. Over 20 different media are distributed throughout FIRST: water of different qualities, neutral and reactive gases and large amounts of liquid nitrogen. Several kilometers of cables distribute electrical power or collect data from controllers and sensors. An automatic surveillance system with over 800 data points monitors the status of the facility including the very important safety infrastructure. Expressed in numbers:

- fresh air input: 45'000 m^3/hour
- maximum cooling power: 650 kW
- installed electrical power: 350 kW
- liquid nitrogen consumption: 500'000 liters/year
- 28 sensors for toxic gases

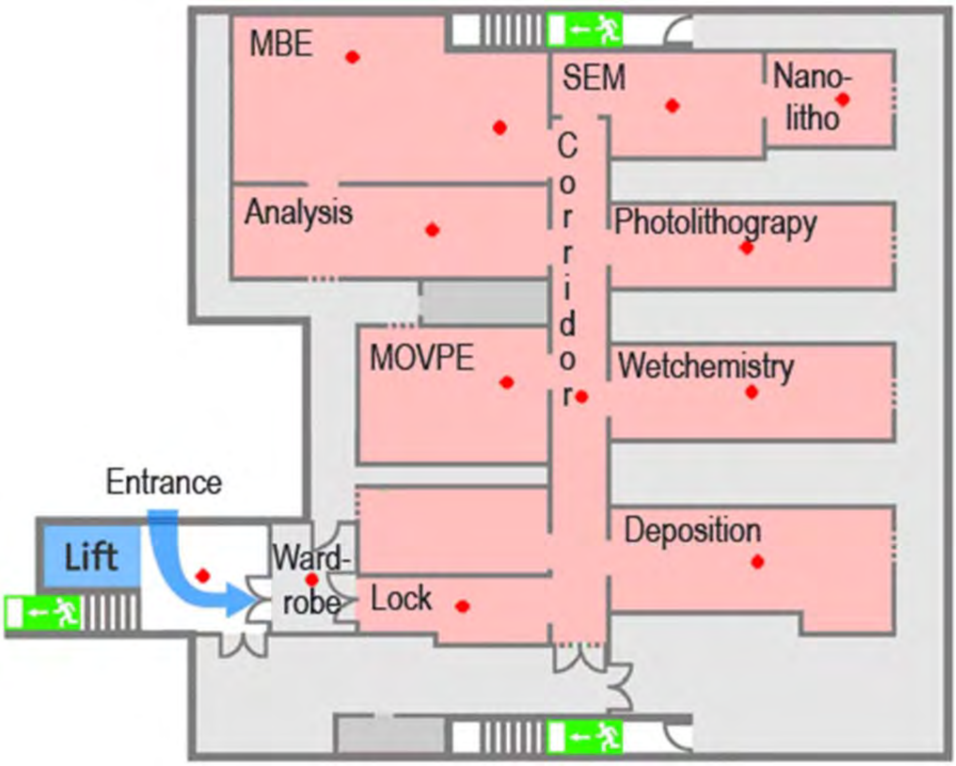


Figure 17:
Layout of FIRST cleanroom area.

As long as the infrastructure works well, hardly anyone will notice its complexity. The FIRST operation team is in close contact with the users in order to optimize the cleanroom conditions in respect to air quality and economy of resources.

Even after 10 years of operation we could improve the technical infrastructure. By replacing some sensors and adapting the control software we were able to save a significant amount of energy in 2011. Because FIRST is situated deep in the ground the intrusion of leak water has always been an issue. By concrete injections this problem has further been reduced. The

installation of a heating unit in a gas room and additional illumination in our chemical storage room have improved the working conditions for our support team.
Our Lifeline II gas detectors are no longer supported by the supplier; all sensors of this type have been replaced by MIDAS sensors.

In 2011, FIRST staff developed and installed an overfill protection for the chemical disposal. Disposed acids and solvents from the wet benches are collected and disposed in metal or plastic containers. Optical and capacitive sensors contactless measure the filling state. However, plastic containers suffer from decreasing transmission properties due to aging and contaminations. The filling state control did not work reliable anymore. In addition, different kind of sensors complicated the operation. Therefore, a new control system was developed based on the weight of the container. This allows for independence of transmission properties of the liquid, kind of container and of the specific weight. A counter weight is installed in a way that a signal is initiated as soon the container is full. A flashing LED light indicates that the container needs to be exchanged. The weighing system can be integrated into commercially available overfill protection containers.
Contact for further information: Christian Fausch

A big improvement has been achieved on our fire detecting and evacuation system. Fire detection sensors have been replaced and were grouped for easy display of the origin of a generated alarm. The fast evacuation of the lab is ensured by the installation of additional fire alarm horns and regular evacuation exercises.

After almost 10 years of odyssey a permanent solution for office space for the FIRST team has been achieved. We got a permanent commitment for the room HCI D 115 in exchange of the time limited room HCI F 143. With the only exception of HCI E 121 all offices of the FIRST team are now in the D-floor of finger 1 in the HCI building. The vicinity of the offices to the cleanroom ensures efficient work with fast response time to spontaneous user requests and emergency circumstances. The users easily find the technicians; the administrative efforts can be minimized. We are looking forward to enjoying our ‘homes’ for many years.

Education and use of the lab

General seminars

The **introduction day** comprises general and access information, cleanroom basics, infrastructure information, safety training, cleanliness seminar, chemistry seminar and safety test. So far, 554 users were trained by FIRST staff in the introduction day over the past six years (Figure 18). The introduction day is mandatory for each user who intends to use the FIRST cleanrooms independently of level of experiences. Particularly, safety rules and escape routes are unique to each lab and need to be understood by each user. This will be verified by the safety test at the end of the day which each user has to pass. Introduction days will take place every four to six weeks. Interested parties need to register online. Access to FIRST is based on approved projects only which is in the responsibility of the corresponding group leader (Professor). In 2011, 97 new users were trained during nine introduction days.

Contact for further information: Silke Schön, Tracy Napitupulu

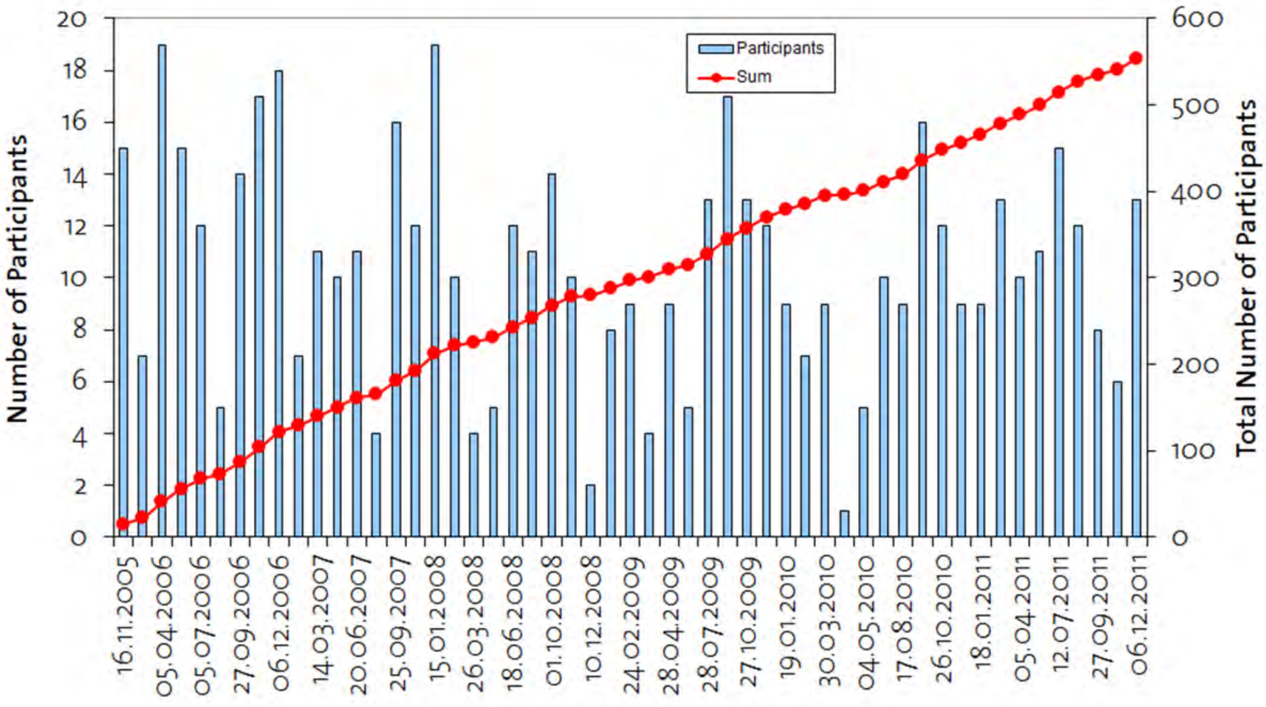


Figure 18:
Number of the participants trained during the introduction day displayed per seminar over the past six years (blue bars, left axis) and summed (red line, right axis).

A cleanroom is much different from a normal lab. The demands for cleanliness and reproducibility are tremendously high. That requires a high level of professionalism of all FIRST users such that their behavior does not interfere with other users work. Therefore, each new

user has to take part in the **cleanliness seminar**. Even though the environmental parameters such as particle concentration, temperature, humidity and overpressure are controlled by the technical cleanroom infrastructure, the main impact is caused by the people being present in the cleanroom. To work clean and efficiently in FIRST, all users must be well trained and must know how to behave according to the environmental specifications. This seminar provides a short introduction into general cleanroom behavior. It teaches how to dress properly, when to wear gloves, what is allowed to bring into the cleanroom and how it needs to be cleaned beforehand from dust particles and other relevant contaminations.
Contact for further information: Maria Leibinger, Petra Burkard

Over the years, we noticed that many of our users have only little experience in safe and controlled handling of chemicals and in carrying out chemical reactions. However, in Micro- and Nanoscience, they need to be able to master complicated process steps using different kind of acids and solvents in order to produce their devices and nanostructures. Therefore, we developed a **chemistry seminar** which is tailored to the chemical processing needs of our users. It teaches the chemistry of basic acids, bases and solvent, their danger potential, basic chemical reactions for cleaning and etching of semiconductor, danger symbols, and the safe handling of these chemicals.
Contact for further information: Sandro Bellini

Every new FIRST user is required to have a **mentor** that supervises him during the first six months of work in the cleanroom. The mentor system in FIRST was established in FIRST in 2007 to cope with the constantly increasing number of users and the corresponding training effort. The duties of a mentor are complementary to the duties of equipment responsible staff. Preferably, mentors are recruited from the group of the new user. They are usually experienced FIRST users. FIRST mentors are appointed by the FIRST operation team. The mentor is co-responsible for the proper cleanroom behaviour of her/his trainee and should help her/him to define appropriate process flows to account for the interference of unit process steps, their competing influence on device performance and their influence on equipment performance. In order to reach this goal, the mentor helps the trainee to efficiently develop the first processes, taking safety, contamination and cleanliness requirements into account. The mentor spends the first working days of her/his trainee together with her/him in the FIRST lab and teaches the trainee cleanroom adequate behaviour (e.g. cleanliness and work hygiene, tidying up after finished work, causing minimal laboratory pollution, supply and disposal of consumables, checking of working parameter of machines, a.s.o). The mentor is contact person for her/his trainee in case of work related questions and problems. She/he encourages the trainee to ask him/her in case of any questions and problems. In 2011, about 35 FIRST users served as mentors for new users.

Contact for further information: Silke Schön

All **equipment responsible** staff takes part in a seminar at the beginning of their appointment to learn about their rights and duties. Information on general maintenance procedures, ordering spare parts, IT infrastructure issues and information management are provided to prepare the equipment responsible persons for their tasks in the FIRST cleanroom.

Special seminars and technological experience exchange

In November FIRST-Lab and Raith GmbH invited Electron Beam Lithography (EBL) involved people for a one-day **EBL workshop** to the ETH Science City. The event took place in the HIT building in a familiar atmosphere.

The workshop's focus was on the daily EBL work – with a lot of interesting applications and results. About forty users of Raith EBL systems from all over Switzerland and from different fields of applications were present. In addition to the sixteen specific EBL talks presented by users, we had presentations of two different resist suppliers and two application specialists form Raith GmbH.

Contact for further information: Petra Burkard, Sandro Bellini

Figure 19:
E-beam lithography workshop at ETH Zurich in November 2011.

FIRST Lab organized the 2nd seminar on **Electrostatic Risks in Robotic Assembly Manufacturing Processes for modern Microelectronics** in order to teach the students on how to deal with the impacts of electrostatic discharge (ESD) on microelectronic devices during the manufacturing. This seminar addressed all users who are working with sensitive microelectronic devices and

samples. It introduced into the basics of electrostatics by means of various experimental demonstrations and lectured on the different kinds of ESD-damages and their impacts on semiconductor devices with respect to functional and reliability influences. Furthermore, techniques and methods for ESD-risk evaluations of modern robotic process tools were discussed. Critical assembly processes were explained as well as solutions to avoid electrostatic charging. Different experiments were also shown to introduce specific measurement techniques for damage evaluation.
Contact for further information: Hansjakob Rusterholz

The FIRST staff used the annual off-site to visit the Bosch cleanroom facility in Reutlingen, Germany. The impressive infrastructure of the industrial cleanroom of Bosch, the exchange of experiences on running a big-sized cleanroom and interesting discussions were motivating and inspiring. The off-site was completed by a visit of the facilities of the company Microclean which is our contractor for professional overall cleaning.

Beside general cleanroom and equipment-specific training FIRST staff is also involved in lecturing. An overview of cleanroom basics, material characterization and processing is provided in a **lecture** of the lecture series **on nanotechnology** coordinated by Prof. Viola Vogel which takes place each spring semester. Since 2010, a new **lecture series** is taught **on semiconductor materials** by Dr. Silke Schön and Prof. Werner Wegscheider in order to provide the theoretical background for the technologies and methods offered in FIRST. Theoretical fundamentals of semiconductors, basic fabrication methods of bulk materials (e.g. for wafers), epitaxial fabrication techniques and in situ characterization are taught each fall semester. Chemical, structural, electronic and optical characterization techniques as well as deposition methods, optical and E-beam lithography are discussed in the spring semester. In addition, an overview on semiconductor devices such as bipolar and field effect transistors, light emitting diodes, lasers and solar cells based on semiconductor materials is taught.
Contact for further information: Silke Schön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Visits and Public Relations

The FIRST lab cleanroom is attractive to all kind of visitors. FIRST staff and users support professional visits to demonstrate our highly sophisticated technology platform. Professional visitors are scientific collaborators, PhD candidates or representative from politics or funding agencies. Because each person will bring additional particle to the cleanroom we do not allow group visits inside the cleanroom but restrict them to the service area where big windows allow viewing the equipment and processes inside the cleanroom. Visitors need to be announced well in advance and should never be left alone during their stay in FIRST for safety reasons. The visit is kept on file.

In 2011, FIRST hosted more than 400 visitors. One highlight was the department's day of the physics department in summer when many staff members visited our facility.

Contact for further information: Silke Schön

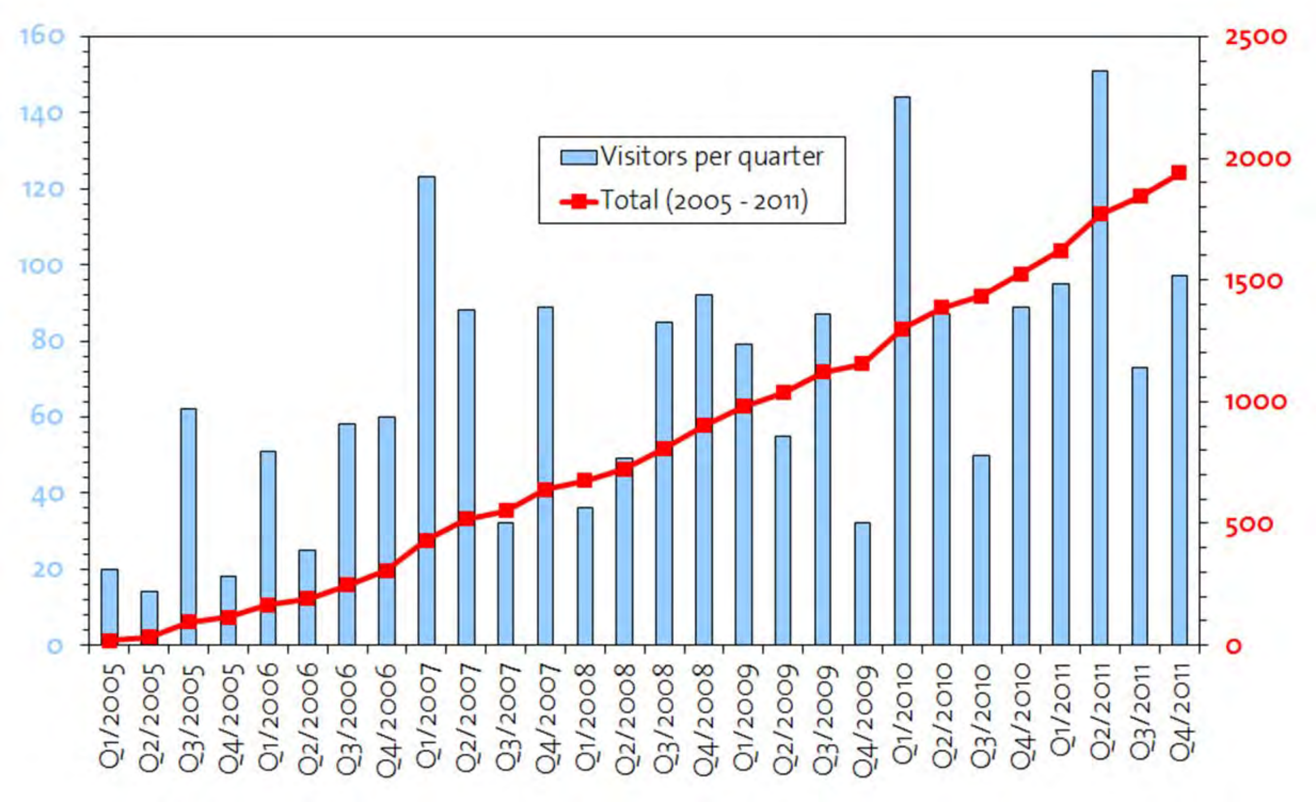

Figure 20:
Number of visitors in FIRST over the past seven years displayed by number per quarter (blue bars, left axis) and summed (red line, right axis).

Research in FIRST

FIRST is a centralized technology platform in the field of micro- and nanoscience. It is open to all users inside and outside of ETH Zurich. FIRST is mainly financed by the executive board of ETH. However, using FIRST is not free of charge. Please note that FIRST is a user lab and our service I restricted to teaching users equipment operation, to support with our technology know-how and to maintain the scientific and technical infrastructure. We do not develop processes like a service lab. In order to benefit from the superior infrastructure of FIRST cleanroom, the university or industrial partner has to file a project with the FIRST operation team. After an initial project discussion a detailed written description of the technical processes and of the equipment to be used is stringently required because the FIRST operation team needs to judge on feasibility, compatibility and equipment availability. The FIRST operation team will provide a cost estimate. Contracts are typically agreed on for one year starting January 1. However, new proposals will be accepted at any time throughout the year without any submission deadline. Once the contract is signed by both parties the introduction day can be visited by the prospective users and the work in the cleanroom can start afterwards.

Contact for further information: Silke Schön

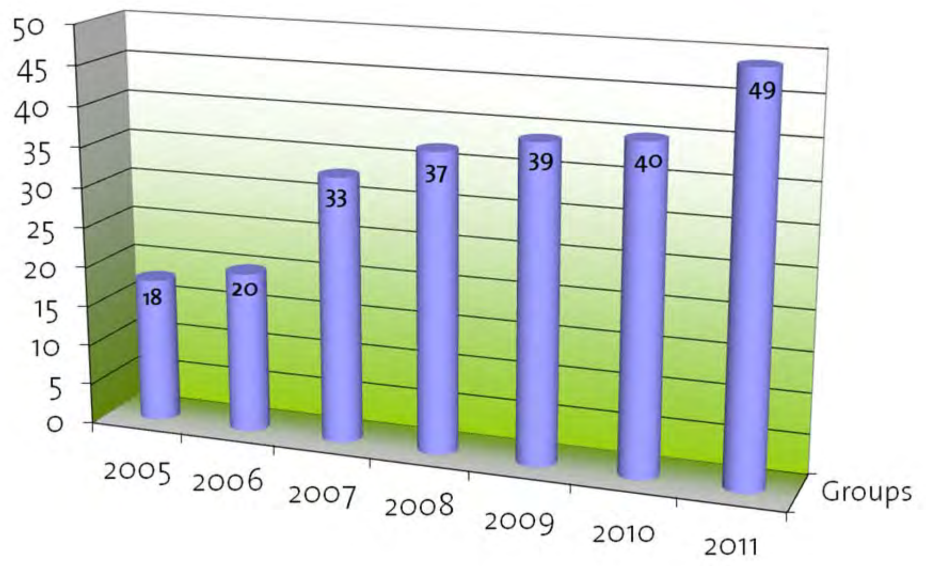

Figure 21:
Number of groups in FIRST over the past seven years demonstrating the on-going high interest in this technology platform.

In 2011, FIRST staff welcomed 49 different groups from universities and industry with over 50 projects to benefit from our unique technical infrastructure for their research (Figure 21).

In the following, a list of all projects with the coordinates for the groups is provided.

ETH Projects (FMT)

1. Prof. C. Bolognesi, Terahertz Electronics Group, D-ITET:
   http://www.ifh.ee.ethz.ch/
   - Terahertz InP/GaAsSb Double Heterojunction Bipolar Transistors (BOL1)
   - InP/GaInAs Low-Noise Pseudomorphic High Electron Mobility Transistors (BOL2)
   - AlGaN/(Ga,In)N Heterostructure Field-Effect Transistors (BOL3)

2. Prof. J. Dual, Institute for Mechanical Systems, D-MAVT:
   http://www.ifm.ethz.ch
   - Mechanics of Micro- and Nanostructures (DUA4)

3. Prof. K. Ensslin, Nanophysics, D-PHYS:
   http://www.nanophys.ethz.ch
   - Nanophysics (ENS5)

4. Prof. J. Faist, Quantum Optoelectronics Group, D-PHYS:
   http://www.qoe.ethz.ch/
   - Intersubband quantum optoelectronics (FAI5)

5. Prof. C. Hierold, Micro and Nanosystems, D-MAVT:
   http://www.micro.mavt.ethz.ch
   - CNTs, NEMS and MEMS (HIE6)

6. Prof. A. Imamoglu, Quantum Photonics Group, D-PHYS:
   http://www.iqe.ethz.ch/quantumphotonics
   - Nanostructures (IMA4)

7. Prof. H. Jäckel, Electronics Laboratory, D-ITET:
   http://www.ife.ee.ethz.ch
   - Photonic bandgap engineering for dense optical integration / Photonic crystals for active optical devices (JAE2)
   - InP-based all-optical sub-ps switches for Tb/s optical communication (JAE4)

8. Prof. U. Keller, Ultrafast Laser Physics Lab D-PHYS:
   http://www.ulp.ethz.ch
   - Sesam, VECSEL and MIXSEL (KEL4)

9. Prof. B. Nelson, Institute of Robotics and Intelligent Systems, D-MAVT:
   http://www.iris.ethz.ch
   - CNT NEMS + Nanocoils (NEL3)

10. Prof. R. Spolenak, Nanometallurgy, D-MATL:
    http://www.met.mat.ethz.ch
    - Combinatorial thin metal film deposition (SPO2)

11. Prof. A. Wallraff, Quantum Device Lab, D-PHYS:
    http://www.solid.phys.ethz.ch/wallraff/
    - Superconducting Qubits (WAL4)

ETH Projects (non-FMT)

12. Prof. M. Ackermann, Institute of Biogeochemistry and pollutant dynamics, D-USYS:
    http://www.ibp.ethz.ch/
    - Fabrication of microfluidic devices for controlled growth of bacteria (ACK1)

13. Prof. Y. Barral, Institute of Biochemistry, D-BIOL:
    http://www.bc.biol.ethz.ch/
    - Development of microfluidic platforms (BAR1)

14. Prof. B. Batlogg, Physics of New Materials, D-PHYS:
    http://www.pnm.ethz.ch
    - Novel organic semiconductors for thin – film transistor applications (BAT1)

15. Prof. C. Degen, Spin Physics and Imaging, D-PHYS:
    http://www.spin.ethz.ch/
    - Fabrication of diamond cantilever and magnetic nanopillar (DEG1)

16. Prof. A. de Mello, Biochemical Engineering, D-CHAB:
    http://www.demellogroup.ethz.ch/en/index.php
    - Microfluidic devices for cell-based enzymatic assays (DEM1)

17. Prof. P. Dittrich, Laboratory of Organic Chemistry, D-CHAB:
    http://www.dittrich.ethz.ch
    - Fabrication of microfluidic master structures *(DIT1)*

18. Dr. M. Döbeli, Ion Beam Physics, D-PHYS:
    http://www.ams.ethz.ch/
    - Silicon Nitride membranes for ion beam physics (DOE1)

19. Prof. L. Gauckler, Nonmetallic Inorganic Materials, D-MATL:
    http://www.nonmet.mat.ethz.ch
    - OneBat – micro solid oxide fuel cell (GAU1)

20. Prof. D. Hilvert, Laboratory of Organic Chemistry, D-CHAB:
    http://www.protein.ethz.ch
    - Microfabrication of PDMS microfluidic chips (HIL1)

21. Prof. J. Home, Trapped Ion Quantum Information Group, D-PHYS:
    http://www.tiqi.ethz.ch/
    - Trapped-ion quantum information (HOM1)

22. Prof. J. F. Löffler, Laboratory of Metal Physics and Technology, D-MATL:
    http://www.metphys.mat.ethz.ch/
    - Composite doped meta-materials (LOE1)

23. Prof. M. Niederberger, Multifunctional Materials, D-MATL:
    http://www.multimat.mat.ethz.ch/
    - Fabrication of microfluidic devices for droplet nanoparticles synthesis (NIE1)

24. Prof. D. Norris, Optical Materials Engineering Laboratory, D-MAVT:
    http://www.omel.ethz.ch/
    - Template Stripped Solar Cells (NOR1)

25. Prof. H. G. Park, Institute of Energy Technology, D-MAVT:
    http://www.iet.ethz.ch/
    - Microfabrication of Carbon Nanotube Nanofluidic Platforms (PAR1)

26. Prof. D. Poulikakos, Laboratory of Thermodynamics in Emerging Technologies, D-MAVT:
    http://www.ltnt.ethz.ch/
    - Measurement of Thermophysical, Electromechanical and Transport Properties of Individual Carbon Nanotubes (POU1)

27. Prof. M. Rudin, Molecular Imaging and Functional Pharmacology, D-ITET:
    http://www.biomed.ee.ethz.ch/research/molecular_imaging
    - Microfluidic chip for microdialysis with chemical detection through fluorescence (RUD1)

28. Prof. V. Sandoghdar, Nano-Optics, D-CHAB:
    http://www.nano-optics.ethz.ch
    - Nanooptics (SAN2)

29. Prof. D. Schlüter, Polymer Chemistry, D-MATL:
    http://www.polychem.mat.ethz.ch/
    - Stacking of two-dimensional polymers (SCL1)

30. Prof. B. Schönfeld, Laboratory of Metal Physics and Technology, D-MATL:
    http://www.metphys.mat.ethz.ch/
    - Near-surface microstructure of Ni-Pt (SCH1)

31. Prof. N. Spencer, Laboratory for Surface Science and Technology, D-MATL:
    http://www.surface.mat.ethz.ch
    - Microfabricated surfaces as platform to study adult and stem cells in designed microenvironments (SPE1)
    - Large-area nanopore-patterned membranes for waveguide and biosensing integrated with on-chip microfluids (SPE3)

32. Prof. W. Stark, Functional Materials Laboratory, D-CHAB:
    http://www.fml.ethz.ch
    - Functionalization of graphene sheets (STA1)

33. Prof. A. R. Studart, Complex Materials, D-MATL:
    http://www.complex.mat.ethz.ch/
    - Fabrication of Microfluidic Devices for Controlled Emulsification (STU1)

34. Prof. G. Tröster, Electronics Laboratory, D-ITET:
    http://www.ife.ee.ethz.ch/
    - *Flexible temperature sensors (TRO1)*

35. Prof. J. van Bokhoven, Heterogeneous Catalysis, D-CHAB:
    http://www.vanbokhoven.ethz.ch
    - Catalysts (BOK1)

36. Prof. H. von Känel, Laboratory for Solid State Physics, D-PHYS:
http://www.solid.phys.ethz.ch/
    - Epitaxial germanium for X-ray detectors (KAE1)

37. Prof. J. Vörös, Laboratory of Biosensors and Bioelectronics, D-ITET:
http://www.lbb.ethz.ch/
    - LBB Nanofabrication (VOE3)

38. Prof. V. Vogel, Biologically Oriented Materials, D-MATL:
http://www.nanomat.mat.ethz.ch
    - Micro- and nanofabrication for biological applications (VOG1)

39. Prof. W. Wegscheider, Advanced Semiconductor Quantum Materials, D-PHYS:
http://www.mbe.ethz.ch/
    - High-mobility (WEG1)

40. Prof. E. Windhab, Institute of Food Science and Nutrition, D-AGRL:
http://www.agrl.ethz.ch
    - Nanomembranes for dynamically enhanced dispersion processes (WIN1)

41. Prof. R. Zenobi, Laboratory of Organic Chemistry, D-CHAB:
http://www.zenobi.ethz.ch/
    - Alumina deposition on silver coated probes (ZEN1)

External Projects

42. Dr. U. Sennhauser, EMPA:
http://www.empa.ch/plugin/template/empa/119/*/---/l=1
    - Nanofabrication for EMPA (EMP4)

43. Dr. J. Gobrecht, PSI:
    - PSI SwissFEL project (GOB1)

44. Prof. G. Patzke, Institute of Inorganic Chemistry, University of Zurich:
http://www.aci.uzh.ch/
    - Metal oxide nanowires for application in portable sensors (PAT1)

45. Prof. A. Schilling, Physik-Institut, University of Zurich:
http://www.physik.uzh.ch/groups/schilling/staff.html
    - Physics of Superconducting Thin Films and Nanostructures and Applications as Single-Photon Detectors (SCI1)

Additional projects with industry.

Collaboration with Industry

The ETH Zurich Board supports collaboration with industry. The main goal is not production, but collaboration in research and development. For this purpose, the industrial partners can profit from attractive rates for the use of the FIRST-lab infrastructure.

In 2011, FIRST collaborated with the following companies:

- ABB Schweiz AG
- Alpes Lasers SA
- Exalos AG
- Enablence Switzerland AG
- Heptagon Micro Optics
- IAF Freiburg
- IBM Research GmbH
- Oclaro Zürich
- Onefive GmbH
- Rainbow Photonics
- SUV-Detectors
- Vibronical AG

The type of collaboration ranged from standard inspection and processing to prototype epitaxial layer delivery, and to proof-of-concept support for innovative processing techniques.

Contact for further information: Silke Schön

FIRST Publications 2011

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Journal of Applied Physics 109 (2011) 073710.

A. Bismuto, M. Beck, J. Faist
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Acta Materialia 59 (2011) 386.

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