Berlin Adlershof
City of Science Technology and Media

Lithography in Adlershof

The Award of Excellence for Innovative Regions by the European Commission

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Introduction

The Science and Technology Park Berlin Adlershof has been growing continuously since its founding in 1991, and is now among the 15 largest worldwide. The natural science departments of the Humboldt-Universität zu Berlin, 12 renown non-university scientific institutes as well as more than 400 technology orientated companies create an unique environment for education, research, development, and production.

Businesses and institutes focus on the fields of

- Photonics and Optical Technologies
- Materials and Microsystems Technology
- Information and Media Technology
- Environmental, Bio-, and Energy Technology.

Five modern technology centers offer companies an infrastructure meeting their demands with flexible office and lab space, supplying special media, and common scientific equipment.

In Adlershof, lithography and its R&D have become a decisive field which impacts microelectronics, microsystems, materials, and sensor technology. This is not only due to the unique scientific equipment available here: BESSY provides the highest brilliant, monochromatic, focused, polarized, synchrotron radiation in the XUV spectral range. A new metrology light source for photons from the IR range up to 1.2 nm wavelength is operated by the Physikalisch-Technische Bundesanstalt.

It is first and foremost the result of the successful interdisciplinary cooperation of scientists, engineers, technicians, and students of different Adlershof institutes and companies. New developments and products like the laser based plasma sources for EUV lithography and metrology as well as the Echelle spectrometer - all of them presented in the following under the label “Made in Adlershof” - figure.

These developments are embedded in a powerful community of applicants of lithography technologies in Berlin. Amongst others, the leading German institute for telecommunications “Heinrich-Hertz-Institut” is located here. Two network organizations - OptecBB and ZEMI - cover the activities of the region in optics and microsystems technology.

Why wait? Adlershof offers you its technical equipment, manpower, and knowledge for common research and development in the field of lithography. It’s an innovative place to solve your scientific and technological problem. We invite you to realize your project in lithography here.

We look forward to your call or e-mail!

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Lithography in Adlershof

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Laser based plasma sources for EUV-lithography and metrology

The step towards 13 nm lithography requires a totally different technology, largely determined by vacuum beam transport, reflective rather than refractive optics, and replacement of today's commercial excimer lasers by either laser- or discharge-based plasma sources yet to be developed. Here MBI's background in plasma dynamics, high-power laser development and X-ray production and detection became essential. A laser-based EUV plasma source results from the interaction of a focused, high-intensity laser beam with a target, heating the small focus spot to temperatures in a range of million Kelvin. Thus, matter is transformed into a plasma accompanied by short wavelength light emission in the EUV and x-ray region. According to industrial system requirements the number of suitable targets is rather limited and mainly determined by their conversion efficiency of laser - into EUV-power, and the lack of debris emission (which rules out almost all solid targets).

At MBI, we have developed and characterized water jets and xenon clusters as possible target systems for EUV-sources. In order to study and optimize these target systems under conditions similar to a commercial source a Nd-YLF burst-mode laser as a model for a high average power EUVL driver laser was used. This laser - originally developed as a photocath-ode driver for state-of-the-art linear accelerators in high energy physics – emits bursts of 800µs duration. Within the burst the repetition rate of single laser pulses can be adjusted up to 1000 kHz, the maximum average power is 5 kW per burst. In addition, pulse duration of the single pulses can be varied in the range from few ps to ns.

The EUV emission of the O-VI (2p-4d) oxygen line at 12.99 nm fits almost perfectly to the peak reflectivity wavelength of Mo/Si multilayers, whereas the Xe emission from highly charged ions form a broad emission band between 10 nm and 14 nm.

A simple high density oxygen target is water, which can be continuously injected into the laser focus in form of a thin liquid jet.
In order to prepare a high density Xe target we make use of the cluster formation process. Up to several millions of Xe atoms can form small spheres of tens to hundreds of nm in diameter, having a local density similar to a solid.

The measured conversion efficiencies (part of laser energy transferred into EUV radiation) range between 0.12% (emission line @ 12.99 nm in water) and 0.8% (in a 2,2% bandwidth @13.4 nm in Xe). As it was pointed out by our investigations both target systems are well suited for a high repetition rate operation up to 125 kHz.

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MBI EUV test stand
The vacuum chamber contains the Xe-cluster/water jet target, a calibrated CCD-camera measures the EUV emission, light comes from the MBI burst-mode laser

Fabrication of Extreme High Aspect Ratio Micro Patterns by Using Synchrotron Light (LIGA)

Fabrication of microstructures for applications in mechanical engineering has been successfully accomplished by the LIGA technology. Here a lithographic pattern transfer into a suitable resist is followed by a galvanic process growing metallic microstructures within the voids of the developed resist. Depending on the actual performance requirements, these metallic parts either are the required mechanical components (Direct LIGA) or alternatively the metallic structures are used as moulds for a subsequent replication process forming plastic components. Within the AZM (Application Center for Microengineering) at BESSY, which is operated jointly with the TU Berlin, equipment and clean room facilities for the entire LIGA process are available.

Micro components by Direct LIGA

X-ray masks and synchrotron radiation can be used for patterning very thick resist layers. Micro parts are subsequently fabricated directly by metallic deposition into the resist forms using an electroplating process. With low cost X-ray masks and resists with high sensitivity, the so called 'Direct LIGA' process enables the cost effective fabrication of micro components with high accuracy. BESSY is using this method successfully for the generation of micro gears for a Micro Harmonic Drive.

X-ray Masks

The mask fabrication is the key technology in the fabrication of HARMS through X-ray lithography. Various mask fabrication techniques have been developed for LIGA technology. Among the different membrane materials, titanium and silicon compound membranes are just a few micrometers thick and have a high X-ray transparency but are expensive and difficult to handle. Beryllium is the most favourable material due to the high X-ray transparency but the potential toxicity is a limitation. At BESSY, technologies using graphite, vitreous carbon or display glass as membrane material have been developed successfully to fabricate X-ray masks.Presently the standard size for X-ray masks is 4" in diameter. In order to increase the mechanical stability, mask membranes are bonded to steel or glass support rings.

Absorber patterns of X-ray masks can be generated in different ways. Most economically the absorber structure is generated by a direct UV lithographical process. This however results in a loss of resolution and quality. Better masks can be generated in a two step process involving intermediate masks. These intermediate masks are fabricated either by direct e-beam writing or by UV lithography into a thin resist layer. Intermediate masks have an absorber pattern of limited thickness and are copied subsequently into thicker resist using synchrotron light. The absorber patterns generated by this two step process are of a superior accuracy compared to the simple process.

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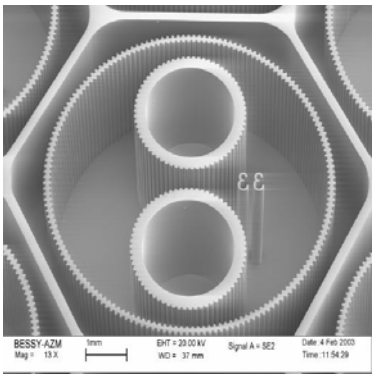
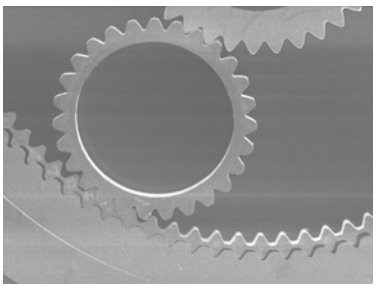


SU-8 resist pattern, 2,7 mm in height



Circular spline, flex spline, planet and sun gear of an Micro Harmonic Drive gear, height: 1 mm (Micromotion GmbH, Mainz)

Metrology

The semiconductor industry has pushed linewidths on integrated-circuit chips down to 65 nm, substantially below the wavelength of 193 nm used for deep UV photolithography. To pattern ever-finer lines, the industry is now preparing the transition to extreme ultraviolet lithography (EUVL) at 13 nm. As EUVL matures, the requirements for the accuracy of metrology measurements are becoming tighter. A high absolute accuracy and worldwide traceability of radiometric measurements is mandatory for a worldwide system development.

PTB has been providing EUV research and calibration services for many years in its laboratory at the electron storage ring BESSY II, where beamlines for reflectometry and detector calibration, irradiation testing, and an undulator beamline for system metrology are in operation. Within the EUCLIDES and MEDEA+ programs of the EU as well as national programs for EUV lithography, high-accuracy calibrations are provided for optical components and detectors in close cooperation with partners from European industry. Reflectometry, especially the measurement of the reflectance of Mo/Si multilayer mirrors for EUVL, is a major activity. For the spectral reflectance of a mirror in the EUV spectral region, a relative uncertainty of 0.14 % is achieved. A large reflectometer enables PTB to characterize EUVL optics up to 550 mm in diameter and 50 kg in mass. Detector calibration is based on a primary detector standard, a cryogenic electrical substitution radiometer. Photodiodes are calibrated as transfer detector standards with a relative uncertainty of 0.26 % by direct comparison to the radiometer.

In cooperation with the Carl Zeiss SMT AG, reflectometry for large curved Mo/Si mirrors is developed and applied. Basic investigations of the radiation hardness of optical components are performed in cooperation with TNO-TPD, FOM-Rijnhuizen, ASML and Carl Zeiss SMT AG. The first European high-resolution EUV prints were achieved by Carl Zeiss SMT AG using undulator radiation in the PTB laboratory at BESSY II. In cooperation with AMTC Dresden, PTB is developing EUV scatterometry for the characterization of mask patterns.

PTB also provides know-how and reference calibrations for the development of laboratory-based instruments for reflectometry of EUVL optics and masks as well as tools for the characterization of EUV radiation sources.

A new EUV radiometry beamline will be installed in 2008 at the dedicated low-energy electron storage ring of PTB, the Metrology Light Source (MLS). It will extend the measurement capabilities towards higher radiant power and variable polarization.

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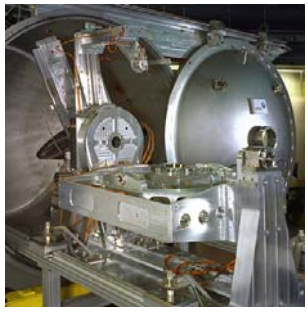

The EUV reflectometer
Background: the open door of the vacuum tank is 2 m in diameter.
Foreground: on a mounting frame – the mechanical system for mirror positioning can be seen. It allows large and heavy mirrors to be aligned with an accuracy of 10 µm and 0.01°.

Echelle Spectrometer ELIAS

The need for more short-wave, intensive and narrow-band radiation sources has put excimer lasers at the center of attention for those enterprises interested in accessing the photolithography market. The availability of the KrF laser with its strong UV line at 248 nm, as well as the far advanced ArF and F_2 lasers at 193nm and 157nm respectively, have led for those lasers to a wider field of applications in photolithography.

Because of their chromatic aberrations, the refraction objectives in the wafer steppers require an extremely high spectral purity of the radiation sources. A strong competitive advantage can be realized by a laser manufacturer who can offer radiation sources with the lowest spectral width.
In connection with this, the highly resolving measurement of laser lines with an intensity dynamic range of up to four orders is of the utmost importance. Deviations in the femtometer range (10^{-15}m) in the halfwidth, as well as in the wings of the lines, must be evaluated precisely and repeatable.

The comparison of the different spectroscopic methods shows that optic arrangements using Echelle gratings are particularly suited for this task.

Together with the Institute for Analytical Science Berlin (ISAS), LTB Lasertechnik Berlin GmbH developed the spectrometric system ELIAS and engineered it for commercial use. By exclusively applying reflection optics with broad-band UV layers, chromatic aberrations are avoided and there are no limitations in choosing the measurement wavelengths up to the DUV (e.g. 157 nm).

The controlling and evaluation software developed by LTB controls all spectrometer and detector functions and allows customers' requirements exceeding the already implemented extensive evaluation routines to be met quickly.

	Wavelength [nm]	***ELIAS LD***		***ELIAS*** I Standard, VUV, Portable		***ELIAS III***	
		Double Pass	Single Pass	Double Pass	Single Pass	Double Pass	Quadruple Pass
Spectral Resolution: Narrowest Spectral Resolvable Line FWHM [pm]	**157**	0.1	0.31	0.083	0.254	-	-
	193	0.11	0.34	0.086	0.283	0.060	0.022
	248	0.15	0.46	0.117	0.376	0.082	0.032
	266	0.19	0.55	0.147	0.428	0.112	0.042
	532	0.37	1.1	0.294	0.856	0.225	0.084
	766	0.59	1.7	0.482	1.4	0.339	0.130
	1064	1.25	-	0.588	1.711	0.450	0.165

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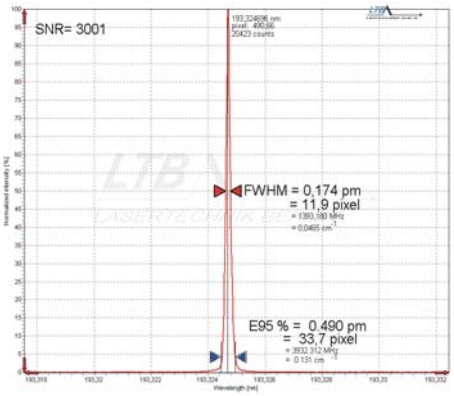

Spectrum of an Excimer Laser
ArF @ 193 nm

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Competence in Lithography

Overview of Research Institutes and Companies

MBI Max-Born-Institute for Nonlinear Optics and Ultra Short Time Spectroscopy

The Max-Born-Institute conducts basic research in nonlinear optics and ultra fast dynamics of the interaction of light with matter and pursues applications which emerge from this research. For these investigations it develops and uses ultrafast and ultraintense lasers and laser based short pulse light sources.

On the one hand, lasers represent a subject of research; on the other hand, lasers are the essential tool used for experimental studies of light-matter interaction. Hence, MBI's research program focuses on

- new sources for ultra short and ultra intense light pulses, pulse shaping, pulse characterization, and measuring techniques for ultra fast processes in a broad spectral range from the mid-infrared to the x-ray region
- ultrafast and nonlinear phenomena with special emphasis on
  - atoms, molecules, clusters and plasmas
  - surfaces and solid state.

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BESSY Berlin Electron Storage Ring Company for Synchrotron Radiation

BESSY operates Germany´s most advanced storage ring facility providing synchrotron radiation in the VUV and Soft X-Ray range for applications ranging from basic research in physics, metrology, chemistry, and molecular biology to materials- life- and environmental sciences also including proprietary research by industry. More than 1000 scientists from over 25 countries come to BESSY annually to perform their research.

As a part of the industry related activities at BESSY the "Application Center for Microengineering" (AZM) is operated jointly with the TU Berlin. This center consists of large clean room facilities for the complete line of processes required for LIGA applications. Within the AZM presently two BESSY beam lines are dedicated to lithography. Both lithography beam lines are equipped with advanced X–ray scanners as exposure tools. Masks and substrates with diameters up to 100 mm can be used for exposures. These beam lines expand BESSY´s service activities for LIGA for high aspect ratio micro structure (HARMS) applications. Ultra thick (more than 1000 µm) resist layers have been patterned successfully. An additional advantage of X-ray lithography is its high resolution enabling the precise fabrication of structures with dimensions in the nanometer range.

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Competence in Lithography

Overview of Research Institutes and Companies

Physikalisch-Technische Bundesanstalt
Photon Radiometry Department

The PTB is the national metrology institute of the Federal Republic of Germany. The tasks entrusted to it cover services in the fields of science and technology rendered to the citizens, to society, economy and science. The PTB thus provides the essential prerequisites for the reliability and further development of measuring techniques applied in these fields. The Photon Radiometry Department of the PTB located in Berlin-Adlershof is responsible for the following tasks:

- Realization and dissemination of radiometric units for photon energies from the UV to the X-ray range
- Calibration of radiation detectors and radiation sources
- Characterization of optical components (mirrors, gratings, filters) and thin layers by reflectometry
- Development and application of X-ray fluorescence analysis.

The Photon Radiometry Department operates a laboratory with nine experimental stations at the electron storage ring BESSY II which cover the photon energy range from 3 eV to 10 keV. Furthermore, radiation from a superconducting 7 T wavelength shifter is used up to an energy of 60 keV. The Metrology Light Source (MLS), the dedicated low-energy electron storage ring of PTB which is located in the close vicinity of BESSY II, started commissioning in April 2007, and is planned to come into user operation at beginning of 2008.

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ISAS Institute for Analytical Science

The Institute of Spectrochemistry and Applied Spectroscopy (ISAS) develops analytical methods with emphasis on spectroscopic determination. One of the core competences of its Berlin Department is the development of spectrometers with high spectral resolution based on echelle gratings. Such a type of instruments has been designed for precise measurements of laser profiles and turned out to be a shooting star on the micro lithography market.

Within 18 months, the ELIAS (Emission Line Analyzing Spectrometer) was developed at the ISAS in cooperation with LTB Lasertechnik Berlin GmbH as well as the Gesellschaft zur Förderung angewandter Optik, Optoelektronik, Quantenelektronik und Spektroskopie e.V. (GOS) Berlin. This instrument offers a spectral resolution in the femtometer region and allows the characterization of excimer laser light used for the chip production. There not only the full width at half maximum of the line profile is of importance, but also the profile of the wings (the so called 95% level). As a result of the new monitoring possibilities, the image definition in the 193 nm wafer exposure process could essentially be improved questioning the need for the 157 nm technology.

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Overview of Research Institutes and Companies

FBH Ferdinand Braun Institut für Höchstfrequenztechnik

The Ferdinand-Braun-Institut explores cutting-edge technologies in the fields of microwaves and optoelectronics. It develops high-frequency devices and circuits for applications in communications and sensor technology. High-power diode lasers with excellent beam quality are produced for materials processing, laser technology, medical technology, and high precision metrology. FBH also conducts basic investigations on nitrides for future applications such as short-waved UV light sources or transistors for very high voltages.

Range of Services in Lithography

- **Design – transforming customer's wishes into layout files**
- **Mask Fabrication – precise structural transfer**
  from 3" x 3" to 5" x 5", resolution up to 1.0 µm
- **Lithography – complete processing in a highly flexible, industry-compatible clean room laboratory**
  high-precision resist structures using direct writing as well as projection lithography and contact lithography in combination with masks or reticles.
  - Stepper Lithography: resolution up to 0.5 µm
  - Electron Beam Lithography: resolution up to 0.25 µm
  - Contact Lithography: resolution up to 1.0 µm

FBH Ferdinand-Braun-Institut für Höchstfrequenztechnik

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Overview of Research Institutes and Companies

LTB Lasertechnik Berlin GmbH

The company LTB Lasertechnik was established in 1990 by scientists and engineers with years of experience in the development and production of lasers and spectrometers.

The company develops, manufactures and successfully markets worldwide:

- high-resolution Echelle spectrometers
- laser-based measuring systems like laser fluorescence spectrometers with wavelength-variable laser excitation and spectrally, time- and spatially resolved fluorescence measuring as well as complete LIBS systems with laser, sample chamber and high resolution Echelle spectrograph and other customized systems
- short-pulse lasers in the sub-nanosecond range for industrial applications (OEM) - Nitrogen lasers, automatic continuously tunable modules for the range 205 nm … 900 nm

Application areas are the excimer laser lithography, laser-induced plasma spectroscopy (LIBS) and fluorescence spectroscopy (LIF), MALDI-TOF mass spectroscopy, cell cutting under the microscope, quality and process control.

LTB LASERTECHNIK BERLIN

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Ifg Institut für Gerätebau GmbH

The IfG was founded in 1993. Our special competence is the design and manufacturing of X-Ray optics both as capillary optics and HOPG-optics. These can be prepared according special user requirements. The energy ranges for poly-capillary optics from a few hundred eV up to 25 keV, for HOPG-optics it is higher than 2.3 keV. Both types of optics can be used for shaping X-ray beams in case of HOPG-optics additionally the X-rays are monochromatic.

IFG Institute for Scientific Instruments

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Competence in Lithography

Overview of Research Institutes and Companies

BESTEC GmbH

In cooperation with Fraunhofer Institute for Material and Beam Technology IWS Dresden, CARL ZEISS SMT AG, Max-Born-Institute Berlin and Physikalisch-Technische Bundesanstalt (PTB) Berlin, BESTEC has supplied an EUV-Reflectometer, where BESTEC was responsible for:

- complete EUV-Reflectometer design
- design and manufacturing of the goniometer and the monochromator
- assembling of the system

The reflectometer is designed as a tool for producers of α-tools for EUV lithography. The maximum weight of mirrors to be tested is 30 kg and the maximum diameter is 500 mm. For the measurement radiation with about 10^7 photons of a wavelength between 10…16 nm per pulse is used.

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Berliner Glas KGaA
Herbert Kubatz GmbH & Co.

BERLINER GLAS offers state of the art manufacture of precision optical components, opto-mechanical and electro-optical assemblies and systems for the semiconductor market, e.g. positioning systems for steppers and lithography equipment. With highly-developed optics and CNC-shaped glass or ceramics, the company serves the entire industry that uses and controls light, particularly in the back end, front end and wafer inspection market. As a manufacturer of vacuum and electrostatic chucks for a wide range of different applications, BERLINER GLAS is supporting the development of standards for these products to support the next generation of lithography market. The technical know-how of Berliner Glass enables the company to achieve an extraordinary high flatness of 20 nm PV (power included) at dimensions of 100x500 mm² by the use of deterministic polishing techniques like Computer Controlled Polishing or Ion Beam Figuring. Light weighting up to 95% depending on material and cooling structures can be included, anti-sticking coatings/structures can be applied. Structured electrodes allow for uni-polar as well as for multipolar electrostatic chucks.

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Overview of Research Institutes and Companies

Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut

In our institute, lithography is applied for the development and fabrication of optoelectronic and photonic devices based on Indiumphosphide, silica and polymers. We have been working in this field for more than 15 years. As a 'working horse' optical contact lithography is used, by which lines and spaces down to 1.0 µm and an overlay accuracy of 0.5 µm are routinely achieved. For the generation of sub-µm patterns and nanostructures (e.g. DFB gratings, HEMT gates, photonic crystal structures) direct write electron beam lithography is applied. A new e-beam writer (Leica EBPG 5000+) was installed in our lab at the beginning of 2003 and has proven its capability to produce minimum feature sizes of less than 30 nm. This system also serves for the fabrication of photomasks.
For in-line process control we have, beneath optical microscopes and a surface profiler, a high-resolution scanning electron microscope and an atomic force microscope at our disposal. All lithography work is performed in a class 10 clean room area.

Fraunhofer Institut Nachrichtentechnik Heinrich-Hertz-Institut

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Optical Institute of the Technical University Berlin

UV – light sources
- high power pulsed solid state lasers for soft x-ray generation
- pulse energies up to 1 J,
- repetition rates up to 50 kHz,
- pulse-widths 100 fs to 100ns
- laser materials and wavelengths: Nd:YAG 1.06 µm
  Nd:YALO 1.08 µm
  TiSa, 700 – 1000 nm
- compact excimer laser development
- capillary discharges

Holographic generation of volume gratings in photoresists
- micrograting for optical data storage
- optical interference setups
- material characterization

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Competence in Lithography

Overview of Research Institutes and Companies

Network "Optec Berlin-Brandenburg e. V."

Initiative from companies and research institutions in Berlin and Brandenburg

One of 7 competence networks in the field of optical technology promoted by the Federal Ministry of Research

85 members

Focus:
- biomedical optics
- optical technologies for transportation and space
- optical technologies for the internet
- UV- and X-ray technologies

Management located in Berlin Adlershof

OpTecBB

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Network „ZEMI - Center for Microsystems Technology"

Association of Berlin Research Institutes

Goals:
- Group the research and development potentials in the field of micro-systems technology
- Develop procedures and products for micro- and microsystems technology and prepare them for the market
- Demonstration products and small series for partners in the industry

Management located in Berlin Adlershof

ZEMI

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Berlin Adlershof
City of Science Technology and Media

Lithography in Adlershof
Edition 2007

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