INDUSTRY AND SYNCHROTRON RADIATION - PROSPECTS USING ANKA

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ABSTRACT

Present and future use of synchrotron radiation by industry in the fields of (micro)fabrication and analysis will be facilitated by novel utilization concepts featuring full service and mixed beamline groups which are foreseen at the forthcoming synchrotron radiation source ANKA.

1 INTRODUCTION

The use of synchrotron radiation for industrial purposes is growing. Main fields include micro systems technology with the LIGA process (The acronym stems from the German words for lithography, electroforming, and plastic molding) as one of the important topics, and analysis. Novel concepts are worked out to facilitate the access of industry to the synchrotron radiation sources and to improve the acceptance of synchrotron radiation based methods and processes. We discuss the situation with reference mainly to the LIGA process that was first developed at Forschungszentrum Karlsruhe and is being pursued at many synchrotron radiation laboratories world-wide by now, but not ignoring the analytical use of synchrotron radiation. The future industrial applicability of synchrotron radiation is addressed using the recently funded project of the synchrotron radiation source ANKA (from Angström and Karlsruhe) at Forschungszentrum Karlsruhe as an example. The impact of the growing demand on the design of synchrotron radiation sources and their use within non-accelerator laboratories or companies is shortly commented.

2 ANKA CONCEPT

While the applications described in the following sections 3 and 4 can be covered as well by quite a few other sources than ANKA the philosophy of ANKA regarding contact with industry is significantly different. Full details on the ANKA concept may be found in ref. [1].

2.1 Technical concept

The accelerator part of ANKA includes a 2.5 GeV electron storage ring injected from a 500 MeV booster synchrotron with a linac preinjector. The design of the accelerator has aimed at cost-effectiveness through compactness and use of proven technology, and at providing high flux, brightness, and brilliance in the X-ray region around a characteristic wavelength of 0.2 nm from bending magnets while keeping options for insertion devices in three dispersion-free straight sections. Table 1 displays the main parameters and shows that ANKA is situated somewhere between 2nd and 3rd generation sources.

Table 1: Main parameters of ANKA

Parameter	Unit	Value
Energy	GeV	2.5
Magnetic field	T	1.5
Characteristic wavelength	nm	0.2
Current	mA	200
Circumference	m	97.2
Number of cells		4
Tunes Q_h/Q_v		6.85/2.88
Chromaticities ξ_h/ξ_v		-15.3/-7.5
Emittance (DDBA lattice)	nmrad	83(43)
Momentum compaction factor		0.0092
RF frequency	MHz	500
Harmonic number		162
Energy loss per turn	keV	642
Lifetime	h	>17
Bending magnet source size (Σ_h/Σ_v)	mm	0.25/0.13
Number of bending magnets		16
Number of free straight sections		3

2.2 Utilization concept

The very center of the ANKA utilization concept is to offer full service in microfabrication and analysis to (industrial) customers which do not need to set aside their own experienced man-power. Thanks to the cost-effective design of the source the cost of this service will be very competitive. Thus, there is virtually no threshold for using this service which will be beneficial particularly for small and medium size enterprises (SME) as well as for non-accelerator companies and laboratories. Prerequisite to offering a state-of-the-art service at industrial standards is a mixed beamline group composed of ANKA personnel and research group members who, together, can satisfy this double requirement. This basic idea is pictured in fig. 1.

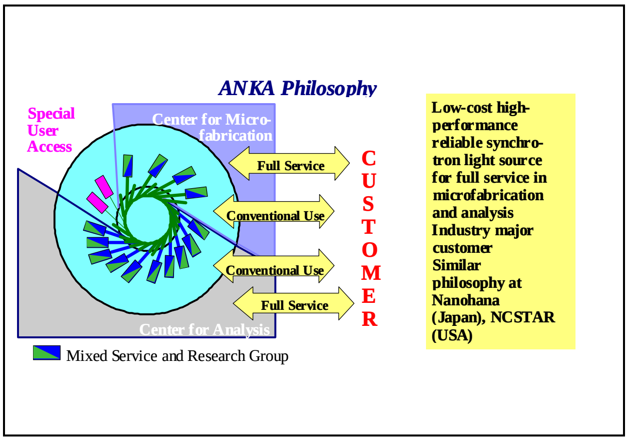

Fig. 1: ANKA philosophy

3 MICROFABRICATION

Among synchrotron radiation based (micro)fabrication technologies LIGA is certainly one of the most widely used. LIGA has been developed from the early eighties at Forschungszentrum Karlsruhe, first in the context of work on gas-dynamic isotope separation based on the separation nozzle[2] [3] [4]. It opens up completely new ranges of freedom in terms of shapes, materials, and production processes of microstructures, and has the potential of mass fabrication. As a consequence, applications of this technology to other fields than the original one were pursued vigorously since the mid-eighties. This led, finally, to the creation of Program Microsystems Technology within Forschungszentrum Karlsruhe which is run to develop and to make marketable microsystems which may contain LIGA microstructure elements[5].

LIGA technology is spreading out rapidly. A number of synchrotron radiation sources in Europe, the United States of America, and East Asia have started LIGA programs. Fig. 2 shows major places with LIGA activities around the world.

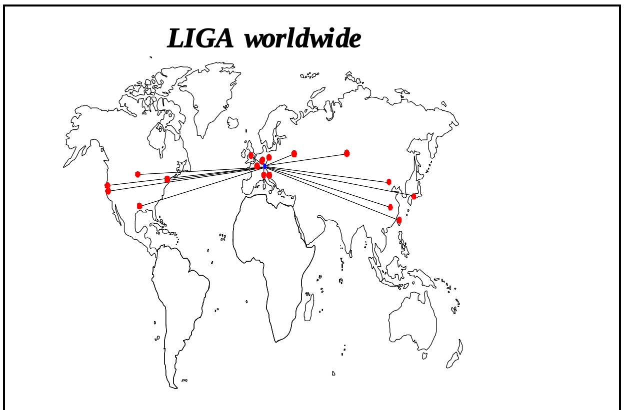

Fig. 2: Laboratories with significant LIGA programs.

More recently, Forschungszentrum Karlsruhe has added a small scale mass-production line to the already existing important LIGA facility and is going to build its synchrotron radiation source ANKA that will have, initially, three LIGA beamlines for developing products and processes. There is also an industrial company specialized on producing and marketing LIGA products[6], and further companies are already using LIGA parts in their products. Thus, technology and products will be increasingly available at various places. Second source concerns of industry can be effectively satisfied. Efforts towards standardization and exchangeability are undertaken both in the US and in Europe.

In the following, we briefly review the basics of LIGA. More details and, in particular, a wealth of pictures, may be found in ref. [5].

3.1 Basics of LIGA

A typical sequence of LIGA process steps starts with lithography using synchrotron radiation from an electron storage ring, followed by electroforming, and ends with molding (Fig. 3). Prerequisite to lithography is mask making and substrate preparation. Prior to molding a mold insert which is composed partly or entirely from microstructure components produced by means of LIGA has to be made. There is a cost crossover, depending on the number of pieces made, of making components directly with lithography or with molding. The cheaper synchrotron radiation lithography is offered the larger will be the number of pieces which can be made economically by using only lithography.

3.1.1 Lithography

Primary pattern are formed preferentially by an electron beam writer in a comparably thin resist (thickness up to 4 µm). If there are less demanding requirements on the critical dimensions, more modest pattern generation may be used, e.g. photolithography with a chromium mask or laser writing. Developing the exposed up to 4 µm thick resist, filling the empty space with gold by electroforming, not higher than the resist, and stripping the unexposed resist leads to the so-called intermediate mask. It is thick enough to be copied by means of soft synchrotron radiation into a 10 to 20 µm thick resist, but is too thin to give enough contrast with harder radiation used for exposure of substrates which are up to several 100 µm thick. Same processing as before results in the so-called production mask which has an absorber thickness between 10 and 20 µm. This mask can be used to expose thick resists in the range of 100 µm up to 1 mm. Still thicker resists can be exposed if the thickness of the gold absorber is increased.

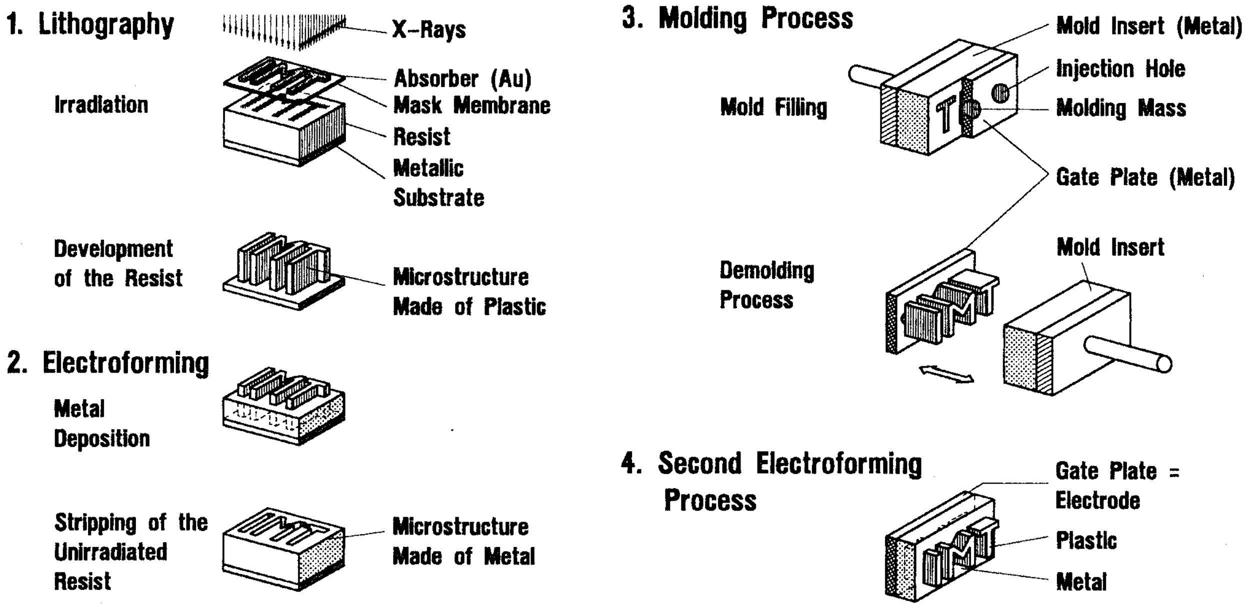

Fig. 3: Schematic of LIGA process

Preferred resist material is poly(methylmethacrylate) (PMMA). It is applied on a metallic or metallized plate in thick layers either by in-situ polymerization, or by gluing slab material onto the substrate. In some cases, free standing slabs of PMMA were used for exposure.

PMMA layers up to 500 µm thick are routinely exposed through the production mask. Limits of the dose deposited at the surface (≈20 kJ/cm^3) and at the bottom (≈4 kJ/cm^3) have to be observed. This correlates the resist thickness with the spectrum in the sense that thicker resists need harder radiation.

3.1.2 Electroforming and molding

Though electrochemistry knows many more metals amenable to electroforming the metals available in LIGA technology so far are Ni, Cu, Au, NiFe, and NiCo. The substrate is either metallic itself or is covered with a thin metal layer to allow start of electroforming (plating base).

Different molding processes and materials have been used. They include transfer injection molding with thermoplastics, both unfilled and filled, reaction injection molding with duroplastics and elastomers, hot embossing under vacuum with thermoplastics above melting temperature, sol-gel process with ceramic precursors, ormoceres[7], and with gelatine, and wet embossing of gelatine slabs[8].

Thermoplastics used so far include PMMA, polycarbonate PC, polysulfone PSU, poly(oxymethylene) POM, polyamide PA, poly(vinylidenefluoride) PVDF, poly(perfluoroalkoxyethylene) PFA, poly(butylene-terephthalate) PBT, poly(phenyleneether) PPE, poly(etheretherketone) PEEK, duroplastics were mainly cast resins on the basis of acrylates, amides, and silicones.

3.1.3 3D structuring

While microstructures can have almost arbitrary contours in the lithography plane only limited by the electron beam writer and some design and process considerations, they can normally not have a shape variation in the direction of the radiation. Topologically speaking, they are confined by cylindrical surfaces. However, an intelligent management of exposure parameters, substrate preparation, and combination of process steps can be used to add significant structures in the third direction, too. In this sense, tilting, rotating, and wobbling of mask and substrate jointly is a means to produce reflecting surfaces, dove tails, grooves and channels, continuous and discontinuous conical structures, to name only a few (fig.4). Combination of molding with lithography, in particular, using aligned molding, allows fabrication of structures with two and more different levels.

3.1.4 Movable parts

Movable metallic parts can be produced using a sacrificial layer technique. In this case, the base plate for electroforming consists of a metal layer like titanium which can be selectively etched away after finishing electroforming. Structures like springs, seismic masses, actuator parts, gear wheels, turbine rotors, etc. have been produced.

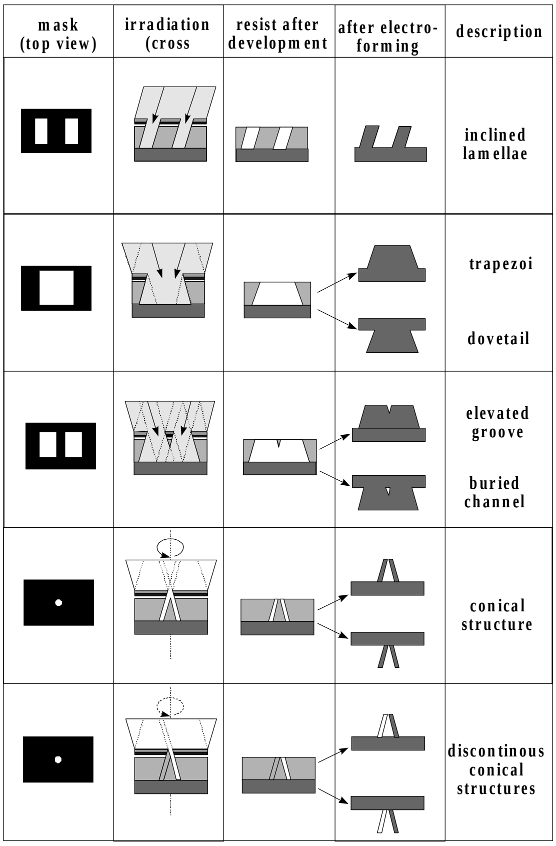

Fig. 4: 3D structuring capabilities through tilting rotating, and wobbling.

3.1.5 Integration

Usually, fully operational microsystems comprising sensors, actuators, and electronics need an integration and assembly of several components. Prominent examples are the LIGA micro grating spectrometer, the accelerometer, the chemical microanalysis system, micropumps and -valves, to name only a few. Quasimonolithic integration of LIGA structures with fully processed CMOS wafers conserving their proper elctronic function has also been demonstrated. To bring all building blocks of a microsystem together automatic assembly methods must be provided for hybrid integration. Prototypes of assembly robots are already operating.

Fig. 5 gives an overview on various systems and components on their way from research to product.

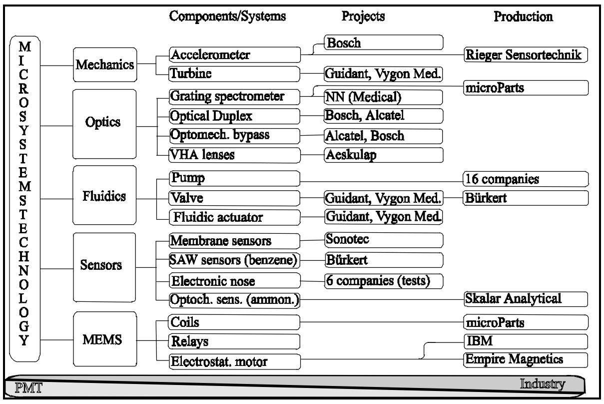

Fig. 5: From research to products (E-motor not from PMT)

3.2 Other fabrication technologies

Besides LIGA, there are various other synchrotron radiation based fabrication technologies which may become of industrial importance. They include X-ray lithography for microelectronics, radiation-assisted removal or deposition of thin films, deep cross-linking of plastics, and deep food sterilization.

4 ANALYSIS

Winning industry for analytical applications of synchrotron radiation is a growing concern for many synchrotron radiation sources. Most experience in this field has probably been accumulated by Daresbury Research Laboratory[9] Their experience, together with that of several other labs, has been taken into account when planning beamlines for ANKA (Table 2). More on analysis may be found in ref.[10].

Table 2: Analytical methods and applications at ANKA

Method	Application
Diffraction (powder, single crystal)	Characterization of materials
Protein crystallography	Structure and function of large biomolecules
Roentgenography	Stress, texture, morphology, and defects in materials
Topography	Quality of crystals
Absorption spectroscopy	Speciation of materials
Tomography	Non-destructive quality control
Fluorescence	Trace analysis
Interfaces (XAS, XPS, XRD, XSW)	„Real“ surfaces and interfaces, electrochemistry
Scattering (SAXS/WAXS)	Meso- and nanoscale structures in materials
Infrared	Chemical analysis and optical properties

Fig. 6 shows fields of industrial interest in analysis versus applications offered by synchrotron radiation.

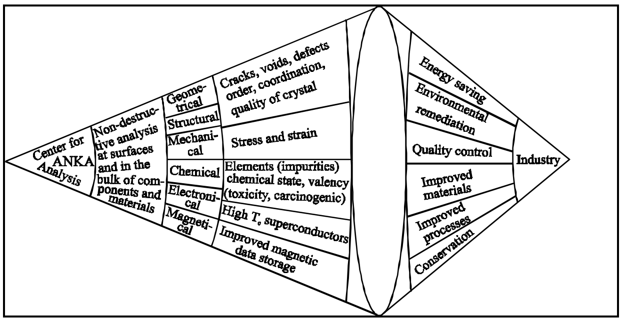

Fig. 6: Industrial demand - analytical offer.

5 EQUIPMENT

The use of services in microfabrication and analysis is not the only aspect of industry and synchrotron radiation. Another important one is the equipment necessary to carry out these services as well on the beamlines' as on the accelerators' side. Inexpensive, reliable, and dedicated apparatus may facilitate market acceptance of services offered. This will, eventually, lead to freshly reconsidering designs of compact superconducting synchrotron radiation sources.

6 SUMMARY

Microfabrication and analysis with synchrotron radiation as well as the fabrication of the required equipment are driving forces to bring industry closer to synchrotron radiation. Offering full service without any sensible threshold, as it is foreseen for ANKA, should favour a growing access of industry.

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