SINGAPORE SYNCHROTRON LIGHT SOURCE – HELIOS2 AND BEYOND

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Abstract

SSLS is using the compact superconducting electron storage ring Helios-2, built by Oxford Instruments, as its source of synchrotron radiation. The scope of applications extends from micro/nanofabrication to the characterisation of materials and processes by synchrotron radiation. Beyond the exploitation of Helios 2 SSLS is working on the development of superconducting miniundulators as key components of future synchrotron light sources.

INTRODUCTION

Originally designed for X-ray proximity lithography in semiconductor manufacturing, the Helios 2 source is catering for a wide scope of applications in micro/nanotechnology and the characterisation of materials and processes. Table 1 shows the main machine parameters.

Table 1: Helios 2 main machine parameters

Parameter	Unit	Value
Electron energy	MeV	700
Magnetic flux density	T	4.5
Critical photon energy	keV	1.47
Circumference	m	10.8
Number of cells/dipoles		2
Emittance	µmrad	1.3
Horizontal beam extension σ_h	mm	0.5 – 1.4
Vertical beam extension σ_v	mm	0.35
Horizontal/vertical tune		1.43/0.63
RF frequency	MHz	55.52
Maximum electron current achieved after ramping	mA	≈450
Lifetime	h	11 - 17
Number of ports		20 + 1
Horizontal angular range/port	mrad	60 (82)

The machine was commissioned in 2000, pilot user operation started in 2001 with the phase contrast imaging beamline, and since October 2003 four beamlines and experimental facilities are in routine user operation as described below. A schematic layout of the current status of the whole facility is given in Fig. 1. Despite the limitations of a lithography machine in terms of brilliance and spectral range, significant results have been achieved during the initial phase of exploitation for a variety of applications.

EXPERIMENTAL RESULTS

Micro/nanofabrication is covered with the LiMiNT facility (Lithography for micro/nanotechnology) while the characterisation of materials and processes relies, currently, on three beamlines, namely, the white-light hard X-ray phase contrast imaging (PCI), surface, interface, and nanostructure science (SINS) in the soft X-ray spectral range, and the hard X-ray diffraction and absorption (XDD). A further beamline for Infrared Spectro/Microscopy (ISMI) is under construction. It will cover a spectral range from 10^4 cm^{-1} to 10 cm^{-1}.

Micro/Nanofabrication

With the LiMiNT micro/nanotechnology laboratory SSLS is capable of doing a complete prototyping as a one-stop shop using the integral cycle of the LIGA process for producing micro/nanostructures from mask writing via either laser direct writing or e beam lithography over X-ray irradiation, development, to electroplating in Ni, Cu, or Au, and, finally, hot embossing in a wide variety of plastics as one of the capabilities to go into higher volume production. The process chain also includes plasma cleaning and sputtering as well as substrate preparation processes including metal buffer layers, plating bases, and spin coating, polishing, and dicing. Furthermore, metrology using scanning electron microscopy (SEM), optical profilometry, and optical microscopy is available. Fig. 2 shows a view of some of the process equipment inside the class 1000 cleanroom of the LiMiNT facility.

Currently, SSLS is focusing on applications to electromagnetic composite materials, photonics, X-ray optics, molecular electronics, and fluidics. Fig. 3 shows an example of a fluid micromixer in SU-8 resist.

Regarding nanolithography capability, SSLS is pursuing two lines of action. One is the development of the super-resolution process which allows reducing the size of clear features by up to a factor of 6 when transferring them from the mask to the resist during the exposure [1]. However, the pitch of the structures is not demagnified by this technique limiting the applicability to special cases. The other one is Extreme Ultraviolet Lithography (EUVL) at a wavelength of 13.5 nm as given by the available multilayer optical components. As this is a demagnifying projection lithography, typically 4x to 5x, all mask features are reduced in size. SSLS is promoting the use of its Helios 2 as a powerful source for EUVL, much more intense than nowadays gas discharge or laser plasma sources, but not delivering the order of 100 W in-band power within a 2% bandwidth around 13.5 nm wavelength as is requested for high-throughput semiconductor manufacturing.

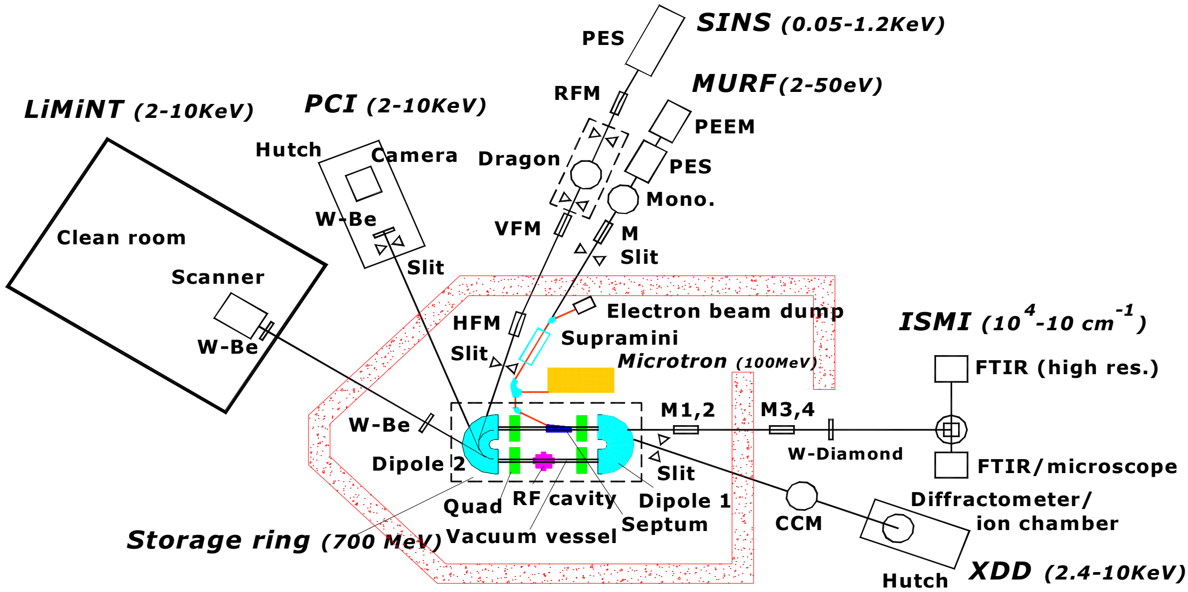

Figure 1: Schematic layout of present facilities at SSLS (MURF is a project study).

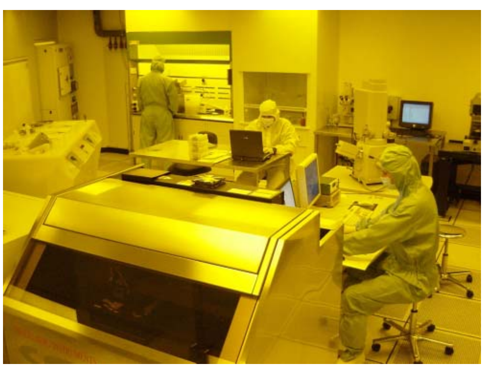

Fig. 2: SSLS' cleanroom with laser direct writer (foreground), electroplating wet bench and sputter equipment (left), chemical hoods, optical metrology, and scanning electron microscope with integrated electron beam lithography (background and right).

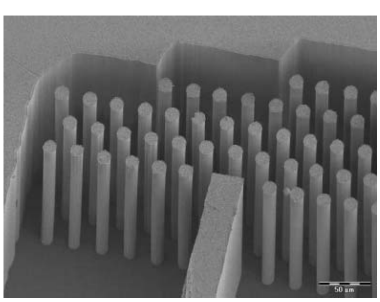

Figure 3: Fluid mixer study in SU-8 resist, 180 µm thick. Scale bar is 50 µm long.

Materials' and Process Characterisation

Currently, three beamlines are in use for materials' and process characterisation. White light phase contrast imaging (PCI) in the 2-10 keV spectral range has been applied to bioengineering [2], biology [3], and water filtration [4]. In the latter case, membrane fouling during the filtration process was studied for the first time *in situ* and in real time. Fig. 4 shows a phase contrast image in transverse direction of a hollow thin fibre made from polyacrylonitrile (PAN) as used in water filtration.

SINS is a Dragon-type beamline with a 4-spherical-grating monochromator [5] covering the soft X-ray range from 0.05 to 1.2 keV for photoemission, absorption spectroscopy (PES, XAFS) as well as X-ray Magnetic Circular Dichroism (XMCD). It is being applied to thin films [6] and nanostructures including powders of nanoparticles [7] and carbon nanotubes on surfaces.

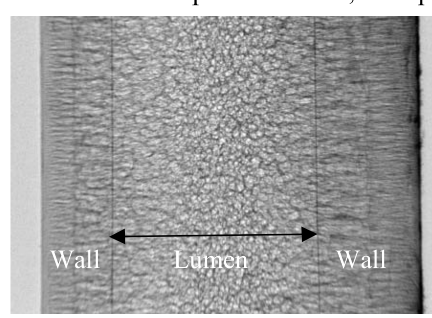

Fig. 4: Phase contrast image of a hollow PAN fibre used for water filtration. The double-layered porous wall varies in thickness from left to right. It encloses the inner lumen or clear bore. Image width is about 1 mm, the fibre axis is vertical. Some fouling deposit appears at the right edge.

XDD provides high-resolution reflectometry, diffractometry and X-ray absorption spectroscopy. Featuring a Si channel-cut monochromator and an Euler 4-circle diffractometer it will be upgraded soon with a toroidal mirror. Highlights include the measurement of the thickness, roughness and porosity of low dielectric constant thin films that are of much interest in present-day semiconductor manufacturing [8,9]. Various plasma treatments during processing can alter and even destroy the low k layers. Fig. 5 gives an example of a high resolution X-ray specular reflectivity curve of a p-SiLK (Dow Chemical) film of 330 nm thickness and 2.1 nm surface roughness after 1 min exposure to a plasma formed from a CH_2F_2/Ar gas mixture. The useful dynamic range spans 5 decades. Inserts show the resolution at small and larger angles.

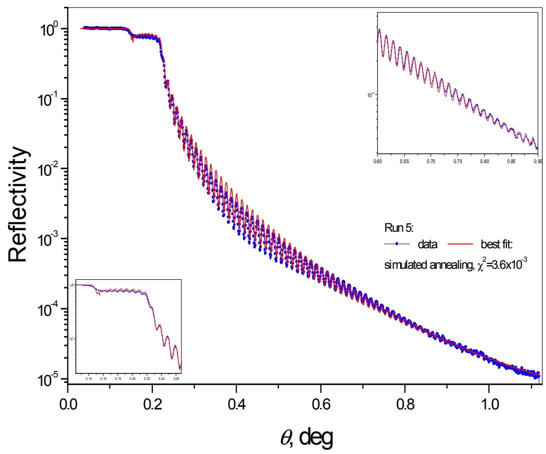

Fig. 5: Grazing incidence specular reflectivity of a p-SiLK thin film on a Si substrate covered with a thin silicon oxide layer.

At the ISMI construction site, the Fourier Transform Interferometer is operational as is a UHV RAIRS chamber for reflectance absorbance infrared spectroscopy in catalytic surface processes. The beamline is going to be contracted soon. It catches IR radiation from an entrance edge source point of dipole 1. The horizontal and vertical angular apertures are 82 and 18.8 mrad, respectively.

Facilities in a planning and proposal stage include small angle X-ray scattering, X-ray imaging microscopy, an extreme ultraviolet lithography test facility, and a time-of-flight photoemission electron microscope.

FUTURE DEVELOPMENT

Besides expanding the beamline portfolio at Helios 2 SSLS pursues its LIULI programme (Linac Undulator Light Installation) aimed at more powerful light sources based on the use of superconducting miniundulators and linacs for FELs and ERLs. The prototype [10] of a 14-mm 50-period supramini is under test at SSLS (Fig. 6). Upon successful completion, it will be installed at the 30 MeV electron linac of SSRF Shanghai in a co-operative effort to study its performance with electron beam, characterise the spontaneous spectral output, and to investigate SASE gain in the spectral range of 2-11 μm (Fig. 7). Work on analytical modelling of supraminis is being pursued as well [11].

Fig. 6: Supramini (centre) during cool down at SSLS. In the background, cryocoolers and power supply.

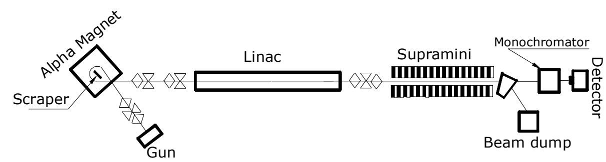

Fig. 7: Planned set up for supramini beam test at SSRF.

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