Nano fabrication with focused ion beams

The development of industrial processes for the patterning of materials on the nano-scale is one of the major challenges of nanotechnology. Lithographic techniques, used at ever shorter wavelengths in the integrated circuit (IC) manufacturing industry, have clearly identified limitations, with minimum attainable feature sizes in the range of tens of nano-metres. Electron beam lithography gives access to smaller feature size. However, scattering of electrons in the target material and in the resist layer imposes limitations on minimum feature size of about ten nano-metre.

Ion beams are in principle well suited to nano-fabrication because ions suffer very little scattering. Ion beams have long been used to modify the topography and the electronic properties of materials in etching or doping applications. By narrowly focusing ion beams, and scanning them across the substrate, the creation of feature sizes in the tens of nano-metre range is possible.

*Nano-fabrication with scanned **focused ion beams (FIB)** is a sequential process. It is therefore much slower than the parallel processes of optical or e-beam lithography and it should not be expected to provide a technology for mass-production of nano-electronics devices. Rather, FIB technology has already found applications in IC manufacture as a complement to other technologies, for relatively small operations on individual chips on the wafer. Examples are failure analysis, or trimming of magnetic read-heads. FIB will find further niches in the fabrication of small series of nano-devices – for example in a research environment - or in customisation of individual devices.*

The Market

The main applications of FIB technology today are all concerned with local ion sputtering - i.e. the removal of material. This requires local ion doses of 10^{20} m^{-2} or higher, usually of gallium ions (with energies of tens of keV). Although estimates of the value of the FIB instrumentation market are difficult to obtain, it is clear that currently the most important manufacturers are US-based.

The essential premise of this project is that for patterning of nano-electronics devices, much smaller ion doses suffice. The FIB no longer relies on sputtering effects, but rather on local defect injection and surface modification at low doses. The target materials in many nano-fabrication experiments (III-V opto-electronic compounds, magnetic thin films or weakly bonded chemicals) exhibit very high ion sensitivity, allowing doses in the 10^{16} m^{-2} range. The lower dose requirement allows a different optimisation of the instrument, leading to strongly improved spatial resolution. Feature sizes below 10 nano-metre (nm) become a possibility.

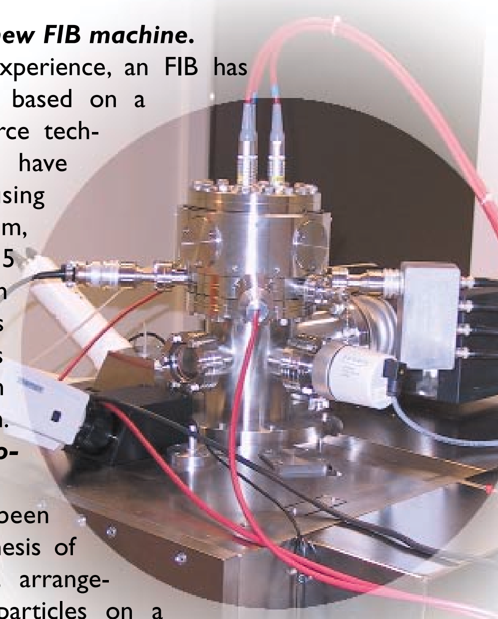
The project has a double interest:

- ***To construct and demonstrate a new FIB machine that can be commercialised.***
- To explore novel scientific applications of the high resolution FIB enabling technology, thereby **opening up new markets for FIB technology**.

Achievements

The project is now in its second year. All targets for the first year have been achieved or exceeded.

The highlights are:



- ***Construction of the new FIB machine.*** Building upon prior experience, an FIB has been developed. It is based on a liquid gallium ion source technique. Initial tests have demonstrated a focusing capability of about 8 nm, for a beam current of 5 pA of 30 keV gallium ions. The machine has the crucial features required for use in professional production.
- ***Patterning of nano-particle arrays.*** A new result has been obtained on the synthesis of nano-devices. Periodic arrangements of gold nano-particles on a graphite surface are produced by depositing pre-formed gold clusters on a surface which has artificial defects, created by low dose FIB irradiation.
- ***Machine time offer.*** In its drive to expand the range of useful applications, the project has offered to make available 15 days of machine operational time to interested European projects. Approximately 3 to 4 experimental proposals will be selected.

The Project Team

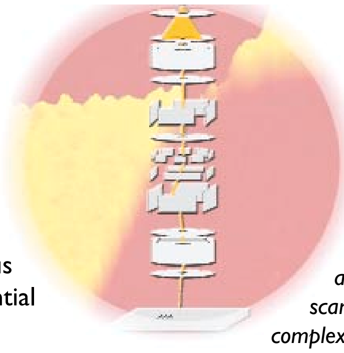
The project team is structured to include the multi-disciplinary competencies necessary for the simultaneous development of the machine and the exploration of potential applications.

CNRS LPN are the central developers and system integrators. They have a long experience in FIB development and use for nano-fabrication. **Raith**, specialising in nano-lithography and navigation products, develop a dedicated platform and exploitation software for the machine, and will have primary responsibility for its commercialisation. **FuG Electronik** develops and contributes the extremely high stability power supplies necessary for ion beam generation and acceleration. **CNRS-CEMES** and **Delft University**, both with a long history in the field of particle optics, are responsible for the design of improved ion source geometry and ion optics concept. **Surrey University** provides theoretical expertise and advice about LMIS physics and development. **CEA** will validate the operation of the ion source in operation inside a 1MeV electron transmission microscope. The **Universities of Essen** and **Paris-Sud** and **CNRS-LPN** are responsible for three already identified FIB application areas, namely:

- Nano-patterning of gold (Au-55) clusters, which act as artificial atoms. This is long-term research, aimed at future nano-electronics devices.
- Nano-patterning of ultra-thin magnetic films. This work is aimed at ultra-high density magnetic data-storage.
- Nano-patterning of III-V opto-electronic materials (e.g. GaAs) to create low-dimensionality systems, or to create photonic bandgap structures in III-V lasers.

An application example

A breakthrough in FIB technology applications will be the demonstration of potential mass production capability. This is no longer utopic. Indeed for nanometre device FIB patterning, the appropriate level of interaction between ions and solids is translated towards low dose effects. In this case, local defect injection now plays the major role, thanks to the very small thickness of the active layers used, and especially to the sensitivity of high quality materials towards ion bombardment. As a direct consequence FIB patterning, using chemical or crystal modification of a surface by local ion bombardment, becomes a high-speed process, offering new possibilities for selective epitaxial growth of materials or selective deposition of nano grains, for example. Such a physico-chemical patterning technique, allowing reproducible and simple pattern transfer, should be one of the major applications for FIB technology in the very near future. The project has started to explore this new application field.



Glossary

FIB: *Focused Ion Beams. A pencil of ions (usually gallium) extracted and accelerated to an energy of several keV is focused and scanned over the surface of a target to define complex patterns.*

Sequential process: *The patterns are written one by one with the pencil of ions. (as opposed to parallel transfer under a mask as in lithography). The possibility of adjusting the patterning characteristics opens the route to "intelligent patterning".*

Direct patterning: *Ion irradiation patterning is a single step process. No additional processing (sensitive resist coating, resist lift-off, metal deposition, chemical etching…) is necessary to produce finalised nano-devices.*

Nano fabrication with focused ion beams

NanoFib
Contract number: G5RD-CT-2000-00344

Start date: 01.01.2001 — End date: 31.12.2003
Duration: 36 months
Project cost: 2 870 000 euros — Funding: 1 540 000 euros

Project co-ordinator:
Jacques Gierak
jacques.gierak@lpn.cnrs.fr

CNRS Laboratoire de Photonique et Nanotechnologie — *Marcoussis (F)*
National research organisation
http://www.cnrs.fr

Raith Gmbh — *Dortmund (D)*
Manufacturer of beam lithography and nano-navigation products
http://www.raith.de

FuG Elctronic GmbH — *Rosenheim (D)*
Manufacturer of specialised power supplies
http:// www.fug-elektronik.de

CNRS CEMES — *Toulouse (F)*
National research organisation
http:// www.cemes.fr

CEA Saclay — *Gif sur Yvette (F)*
National research organisation
http:// www.cea.fr

Delft University of Technology — *Delft (NL)*
Applied sciences university
http:// wwwdo.tn.tudelft.nl

Universitaet Gesamhochschuhle Essen — *Essen (D)*
University
http:// http://www.uni-essen.de/ac_schmid

University Paris-Sud — *Orsay (F)*
University
http:// www.u-psud.fr

University of Surrey — *Guildford (UK)*
University
http://www.surrey.ac.uk

Useful links

http://www.cordis.lu/nanotechnology/home.html
http://europa.eu.int/comm/research/growth/
http://www.cordis.lu/growth

growth infodesk: growth@cec.eu.int

Release May 2002

KI-AC-02-003-EN-C