Factsheet 2: Broad Ion Mill

A Broad Ion Mill (BIM) is an advanced tool used primarily in material science and semiconductor industries for precise material removal, surface cleaning and sample preparation. It utilizes a broad beam of ions to etch and polish the surfaces of various materials. The main objective of BIM in ForRES is to improve delayering techniques to be suitable for modern semiconductor technology. This fact sheet aims to provide a comprehensive overview of Broad Ion Mill technology, covering its key features, how it works and what role it plays in ForRES.

What is Broad Ion Milling?

Broad ion milling is a dry plasma etch method which utilizes a parallel beam of ions to remove material from a sample surface (Fig. 1). The removal is achieved through a physical sputtering process if inert gas like argon is used. It is also possible to employ a reactive gas for ion assisted etching.

The ions are generated in a remote plasma source. They are accelerated to high energies by an electric field and leave the source through a multi-aperture ion optics. The resulting ion stream has a very uniform current density and is highly directional. In order to prevent ion beam decomposition and charge build-up on the sample, the ion beam is neutralized by an electron source. By varying the incidence angle of the beam on the sample the sputtering yield can be tuned (Fig. 2).

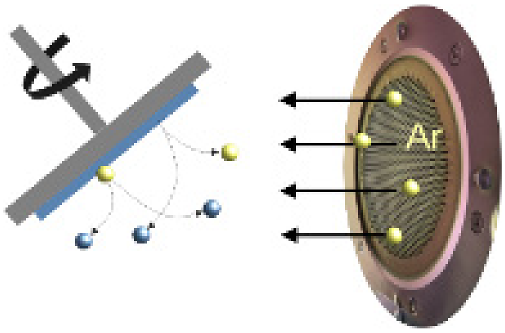


Fig. 1: Schematic representation of the BIM. A parallel beam of argon ions hits the rotating sample under a well defined angle. The incidence angle of the ions can be adjusted to tune the sputtering yield.

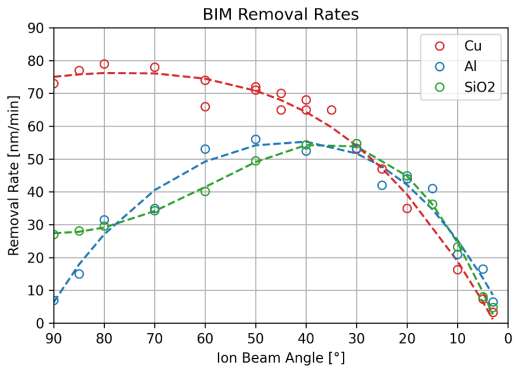


Fig. 2: Measured removal rates as a function of the incidence angle of the ion beam on the sample.

Basic System Components

- **Ion Source and Optics:** Common types are Kaufmann DC (direct current) [1] or RF ICP (radio frequency inductively coupled plasma) [2] ion sources. The advantage of the Kaufmann type is its very well-defined ion energy and the very low energy spread. The electrodeless quartz tube design of the RF ICP source on the other hand is better suited for using reactive process gases. In both cases, a plasma is created from which ions are extracted though a multigrid assembly. The grids also have the task to accelerate the ions to the desired energy and form an ion optical element which creates the parallel ion beam.
- **Sample Stage:** It holds the sample securely and can be set at different angles and positions to achieve the desired milling effect. The sample stage can be tilted and rotated to change the angle of ion incidence, which is important to achieve uniform milling or specific etching patterns. Some holders are equipped with cooling systems to prevent the sample from overheating during milling.
- **Vacuum Chamber:** Ion milling is done in a high-vacuum environment to prevent contamination and ensure efficient ion beam travel. A two stage pumping system consisting of a roughing pump and a high-vacuum pump (e.g., turbomolecular pump) evacuates the chamber to achieve the required low pressure. The vacuum vessel has to be equipped with several ports which allow the introduction of gases, electrical connections, and mechanical manipulations without compromising the vacuum integrity.

Applications

- **Microfabrication:** The ion beam can be used to transfer a mask pattern, e.g. made of photoresist, into the sample. It is a very robust, good controllable technique. The physical sputtering creates structures with high precision and good sidewalls and is an enabling technology to process materials which are hard or impossible to remove by chemical etching.
- **Sample Preparation:** Ion beam milling is ideal for creating thin sections for Transmission Electron Microscopy (TEM) and polishing cross-sections for Scanning Electron Microscopy (SEM). For TEM it is used to thin samples to the required thickness (often less than 100 nm) without introducing artifacts that can occur with mechanical thinning methods. For SEM, samples are precisely polished using ion milling to reveal cross-sections of layered structures, interfaces, and defects.
- **Surface Cleaning:** By physical sputtering surface contamination from materials such as oxides, organic contaminants, or residues from previous processing steps can be effectively removed. Therefore it is useful for preparing semiconductor wafers and other delicate surfaces.
- **Material Analysis:** Ion beams are used in several analytical techniques, e.g. SIMS (secondary ion mass spectroscopy) and RBS (Rutherford backscattering), to probe the composition and obtain elemental depth profiles in the near-surface layer of solids.

Relevance in ForRES

- Enables the removal of very thin layers of material with high reproducibility (Fig. 3).
- Allows processing of all relevant materials with the capability to tune the removal rates for different materials by varying the incidence angle of the ions on the sample surface.
- Provides a cleaner and more controlled material removal process compared to mechanical methods. In many cases outstanding results are achieved when using both methods as complementary techniques taking their specific strength and weaknesses into account.

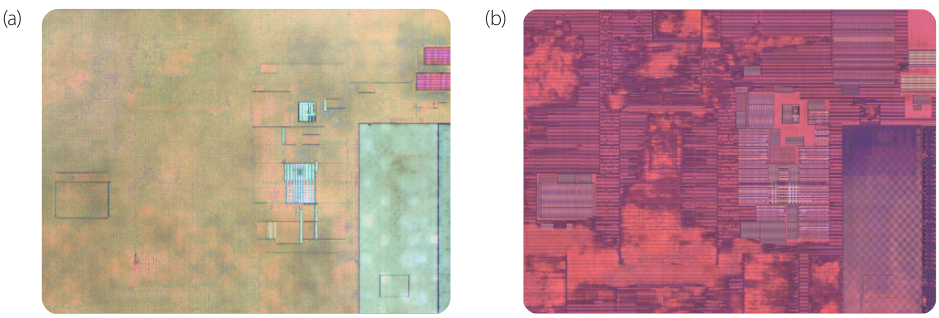
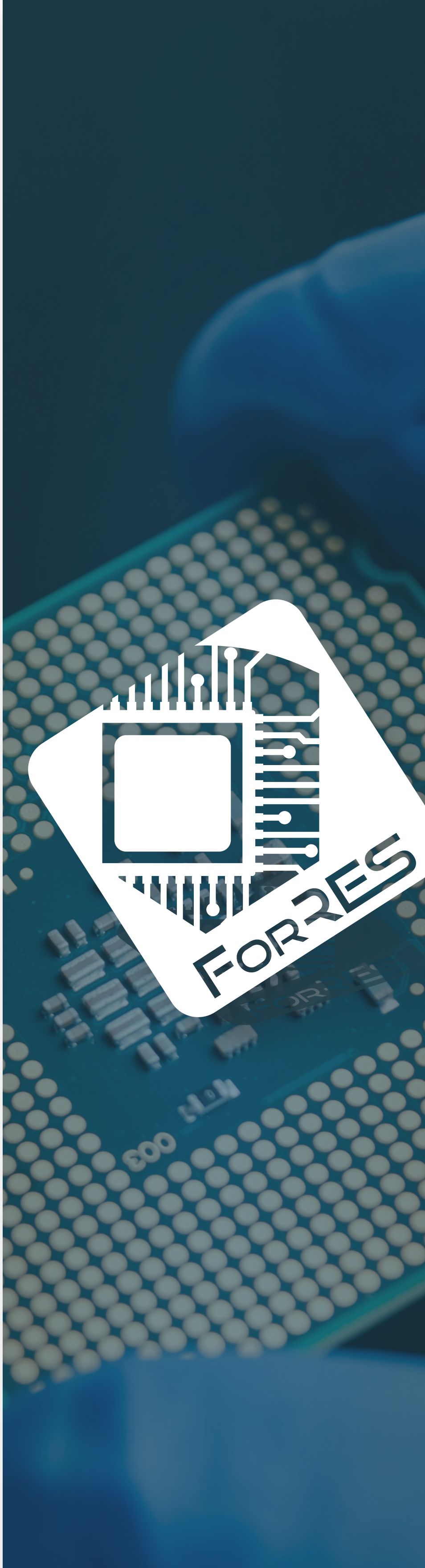


Fig. 3: Chip detail (a) before and (b) after BIM exposure. A thin metal barrier layer of few nm thickness has been removed from the surface clearing the view to the layer underneath.



References:

[1] Kaufman, Harold R. and Robinson, Raymond S., "Ion Source Design for Industrial Applications", AIAA Journal, vol. 20, p. 745, 1982. ***https://doi.org/10.2514/3.51131***

[2] Reed Thomas B., "Induction Coupled Plasma Torch", J. Appl. Phys., vol. 32, p. 821, 1961. ***http://dx.doi.org/10.1063/1.1736112***

Consortium
5 Partners
5 Countries

Budget
€ 2.3 Million
90% EU-funded

Duration
24 Months
07/2023 - 06/2025

Funded by the European Union under grant agreement no. 101102622. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.