Ion Beam-Based 3D Nanopatterning for Multilayer and Micro-Optical Devices

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Nanodevice manufacturing will be faced with new challenges in future applications like quantum computing and/or integrated electro-optical devices for Photonic Integrated Circuits (PIC), such as:

- Processing and patterning of materials that are not used in standard microelectronics applications so far, and
- Generation of localized 3D structures.

Ion-beam etching is a versatile technique that meets the requirements for fabricating 3D nanodevices. Due to its high kinetic energy, ion beam milling (IBM) can pattern all materials through physical sputtering, eliminating the need for specific process chemistry. However, reactive ion beam etching (RIBE) may offer additional benefits, such as increased removal rate or improved selectivity. Furthermore, the anisotropic removal effect at low divergence enables ion-beam technologies to generate three-dimensional nanostructures.

The presentation covers specific applications of ion beam technologies in nanodevice manufacturing.

(1) Ion beam patterning of multilayer-based devices, e.g., tunnelling magnetics resistance (TMR) sensors:

The multilayer composition of the TMR sensor poses issues with the necessary etching required for electrical contacting. Classical dry-etching methods are limited due to the generally poor reactivity of magnetic materials. Additionally, the reactive gas required, such as chlorine, can cause corrosion of the sensor electrodes while in operation. The ion beam milling process uses noble gas ion bombardment to physically remove all materials used in the TMR stack. The ion beam source enables precise tuning of both, the ion density, and the ion energy. Additionally, dry etching with an inert gas, such as argon, voids any corrosion effects that can increase metal resistivity, hence destruct the sensor devices. The so called helium-backside wafer cooling is applied to keep the wafer temperature low enough enabling photoresist processing without resist damage.
Since the ion flux is well determined in terms of energy, energy distribution and directionality, one can achieve well-controlled vertical sidewalls, even in multilayers of various materials. Redeposition on the sidewalls can be counteracted by multi-step etching. This can help to avoid short circuits over thin isolating layers (Fig. 1)
The progress of the sputter etching process can easily be monitored using endpoint detection methods such as secondary ion mass spectrometry (SIMS) or optical emission spectroscopy (OES) (Fig. 2). These in situ diagnostics are indispensable when exact stop or switch points in the process must be met. Examples of the successful application of these techniques will be presented.

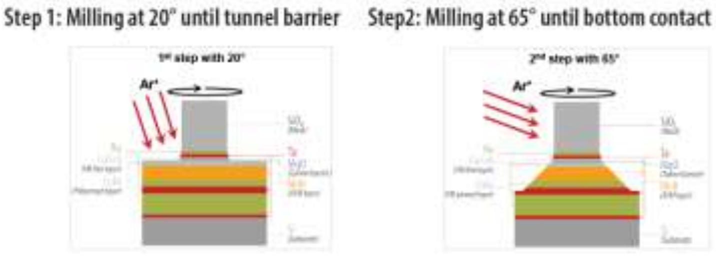

Fig.1: Ion beam etching of TMR stacks at different angles

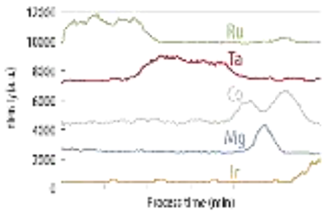

Fig. 2: SIMS scan over time during IBM of a TMR stack

(2) Generation of 3D structures in micro-optical devices:

Sidewall angles of optical devices often need to be adjusted to a defined slope. Even more complex 3D structures are employed in micro-optical devices, such as diffraction gratings and coupling grids. Because of the directional removal of an ion beam, the exact angular orientation of structures can easily be adjusted. For example, a ion-beam process will be used to produce slanted surface relief gratings (SRG) for use as coupling grids in data projection for augmented reality glasses.

Reactive ion beam etching (RIBE) offers unique process advantages to produce SRGs. Slanted structures with a strong defined undercut can be etched, a unique capability of RIBE. Crucial parameters for the RIBE process are selectivity between the mask and the substrate, and control of the geometry between the side wall angle and the bottom angle. By using different chlorinate or fluorinated etching gas mixtures, isotropic as well as anisotropic etching behaviour can be controlled, thereby defining the resulting geometry of the gratings. The ability to independently control ion energy and ion current is also used to adjust the slant shape and selectivity.

Fig. 3: Ion beam etching of SRGs under different angles of incidence

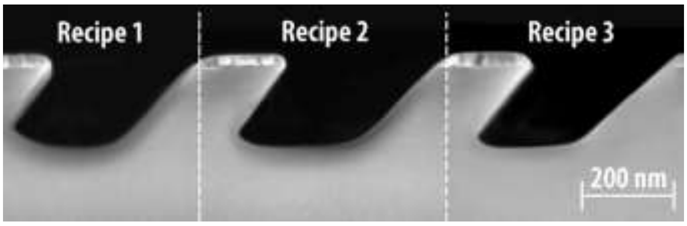

Fig. 4: Isotropic and anisotropic etching by variation of reactive gases, ion energy, and ion current density

Furthermore, this presentation will highlight how ion beam processing is used to produce waveguides for Photonic Integrated Circuits (PICs), providing the accuracy, consistency, and flexibility required for next-generation devices.

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