Fabrication of Sub-micron High Contrast Gratings in Hard Semiconductors or Dielectrics

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Subwavelength gratings are of high interest in optical system because of their unique capabilities to provide high chromatic dispersion, high reflectance or transmittance dichroism and high polarization selectivity. Among sub-wavelength gratings, gratings with a high contrast between the refractive indexes of the slow and fast optical materials, called High Contrast Gratings (HCGs), are of particular interest because of their compact design and very effective optical properties. Many optical systems integrate HCGs, for instance spectrometers, laser beam combiners and polarization-selectivity laser cavity mirrors. However, their accurate fabrication in hard semiconductors or dielectric materials is challenging. A new process-flow was developed to accurately etch any hard dielectric or semiconductor based on hard masking, Reactive Ion Beam Etching (RIBE) and lift-off.

The high contrast of refractive indexes used in HCGs is obtained by a patterned etching process in a layer made of a high contrast dielectric or semi-conductor material. The gratings grooves are filled with air or another gas, or sealed in vacuum to maximize the refractive index contrast of the final structure. As the optical properties of dielectrics and semiconductors have large chromatic variations, different optical materials with a high refractive index must be used according to the wavelength range of interest.

As an example, for wavelengths greater than 1.15 µm in the infrared domain, silicon is commonly used because of the extended process know-how developed for the semiconductor and MEMS industry. Silicon processing tools are broadly available and well-known processes using chemically reactive plasma, Reactive Ion Etching (RIE), enable smooth and deep etching of silicon. However, optical systems using wavelengths shorter than 1.15 µm, for example using visible light, require other high refractive index materials exhibiting a high transparency.

Commonly used materials include the following dielectrics; titanium dioxide (TiO_2), tantalum pentoxide (Ta_2O_5) and Hafnium Oxide (HfO_2). Etching tantalum pentoxide (Ta_2O_5) films is challenging as chemically reactive plasma does not allow an efficient etching process. This is why only Ion bombardments in high-vacuum such as Argon Reactive Ion Beam Etching (Ar-RIBE) allow its nano-structuration. However, a re-deposition of the heavy tantalum atoms is intrinsic to this process. This can be seen on the Scanning Electron Microscopy (SEM) image in Figure 1 after removing the organic nano-imprint resist used for the patterning.

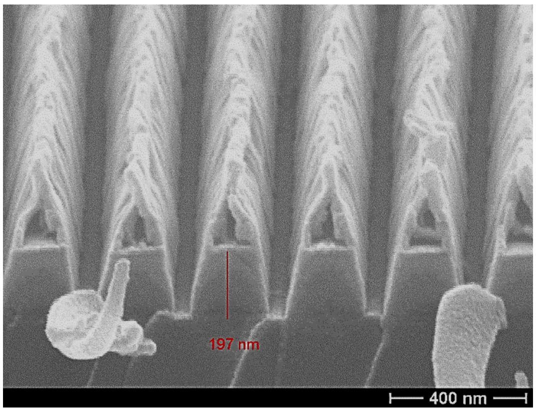

Figure 1: Cross-section image using SEM of a subwavelength grating etched by RIBE in Ta_2O_5 after nano-imprint resist removal by solvent. A massive material re-deposition can be observed on the ridges.

In addition to optical design, CSEM is able to prototype and produce HCGs in hard dielectric and semiconductor materials required by specific and advanced optical systems. Different process steps can be engineered to minimize the re-deposition and to further remove these residues. For example, multiple grazing angles Ar-RIBE allows to etch most of the redeposited material, as can be seen in Figure 2.

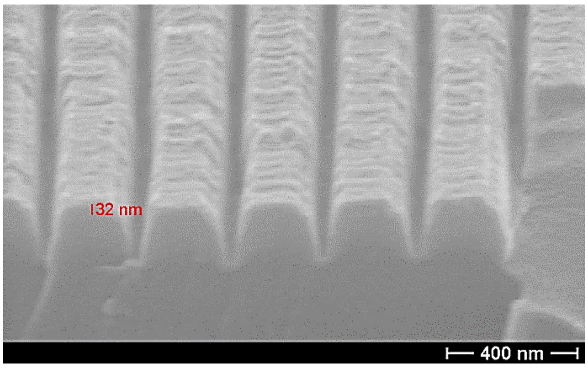

Figure 2: SEM cross-section of a Ta_2O_5 subwavelength grating after top polishing by grazing angle Ar-RIBE.

However, the top interface of the grating layer has still a large roughness making it unsuitable for assembly using bonding with other optical coatings or gratings. In order to minimize the roughness of the top interface of the grating, a combination of hard-masking, Ar-RIBE and lift-off process was developed and optimized, as can be seen In Figure 3.

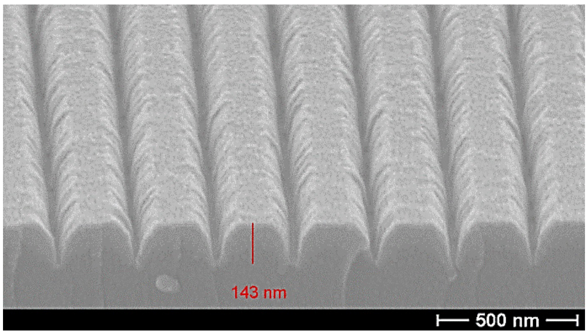

Figure 3: SEM cross-section of a Ta_2O_5 subwavelength grating manufactured by RIBE, hard masking and lift-off. The original top interface of the layer is left intact, enabling a low roughness making it suitable for being bonded.

Using this novel process, high quality sub-wavelength gratings can be manufactured in any hard dielectric or semiconductor material, for which RIBE is an enabling etching process. The top grating interface is the original film top interface, having a low roughness similar to the one of the initial film.