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# Highly Selective Optical Filtering Technology on 300 mm Glass Wafer for Advanced Spectroscopy Applications

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**Abstract:** This paper presents the fabrication and measurements of optical rejection filters, made of dielectric nanogratings developed on 300 mm glass wafer using CMOS process. Their suitability for integrated VIS-NIR spectroscopy applications is assessed. © 2022 The Author(s)

## 1. Introduction

Concerns about environment and health are relentlessly increasing, leading to a demand of sensing resource within everyone's reach. As spectral analysis enables the detection and quantification of numerous chemical species [1], we aim at developing a low-cost technology of multiple parallel optical filters, easy to integrate onto CMOS sensors, and suitable for multispectral applications. An easily fabricated class of filters fit for this purpose are resonant waveguide gratings made of Silicon Nitride ( $\text{Si}_3\text{N}_4$ ) embedded in a Silicon Dioxide ( $\text{SiO}_2$ ) matrix, designed on a glass wafer in ST 300 mm platform. Section 2 presents the design and fabrication of these filters, and Section 3 addresses their experimental performances, corroborated by simulation results.

## 2. Filtering structures

We propose to produce Fano resonances at deterministic wavelengths with periodic 2D gratings, where the primitive cell is square for simplicity. A linear (matrix) relationship then governs the spectrum-signal relations.

### 2.1. Design

To find the approximate ranges of geometrical parameters such as period, diameter, and pattern height, we use the grating equation (1) which links the effective index  $n_{\text{eff}}$  of modes propagating in the structure, the incident wave angle and wavelength  $\lambda$  and the main grating parameters, the period, that determines its reciprocal vectors.

$$n_{\text{eff}} = n_{\text{inc}} \sin(\theta_{\text{inc}}) - m \frac{\lambda}{\Lambda}, m \in \mathbb{Z} \quad (1)$$

Equation (1) [2], directly relates the targeted wavelength  $\lambda$  and the grating period  $\Lambda$ , but more indirectly the pattern's height, that comes through  $n_{\text{eff}}$ . This latter can be coarsely evaluated by considering the nanostructured layer as uniform thanks to effective-medium theory, and by solving the propagative mode of the multilayer stack at the desired wavelength. Parameters are next refined using optical simulation with RCWA method [3].

### 2.2. Filter processing

After the design step, filters are processed onto the ST 300 mm platform, see Fig. 1 for individual steps.

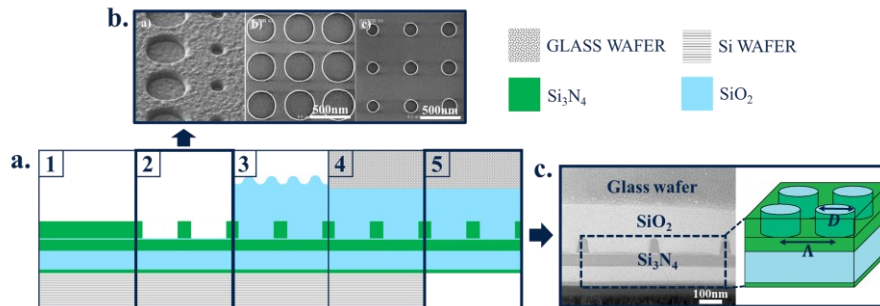


Fig. 1. a) 1-Dielectric deposition on Si wafer: Plasma Enhanced Chemical Vapor Deposition (PECVD) of  $\text{Si}_3\text{N}_4$ ; 2-Photolithography and etching of cylindrical holes; 3-Filling with  $\text{SiO}_2$ ; 4-Chemical Mechanical Polishing (CMP), direct bonding of glass wafer and grinding; 5-Grinding of Si wafer; b) SEM tilted view and top view of round holes in  $\text{Si}_3\text{N}_4$  after photolithography and etching; c) TEM cross-section and 3D scheme of the final structure.

We chose to use only  $\text{SiO}_2$  and  $\text{Si}_3\text{N}_4$  because they are adapted to existing CMOS process flow and they do not absorb visible light, enabling good potential performances in the VIS range.

A process set was used to integrate stand-alone filters on glass Fig. 1.a, using steps that can be integrated directly on top of CMOS processed wafers as well. Structures are obtained by photolithography and etching of cylindrical holes into a  $\text{Si}_3\text{N}_4$  layer Fig 1.b. Holes are filled with  $\text{SiO}_2$  that is then planarized to transfer structures on glass wafer by direct bonding. Finally, initial Si substrate is removed Fig. 1.c.

### 3. Results

Fabricated gratings are measured on a dedicated bench at CEA Leti. Each sample is a  $1 \text{ mm}^2$  square, which contains 100 patches of  $100 \times 100 \mu\text{m}^2$  as seen in Fig. 2.a; each of them is a 2D grating with specific  $\Lambda$  and  $D$ . Filtering structures are tested with a microspectrometer, whose source is a white halogen lamp.

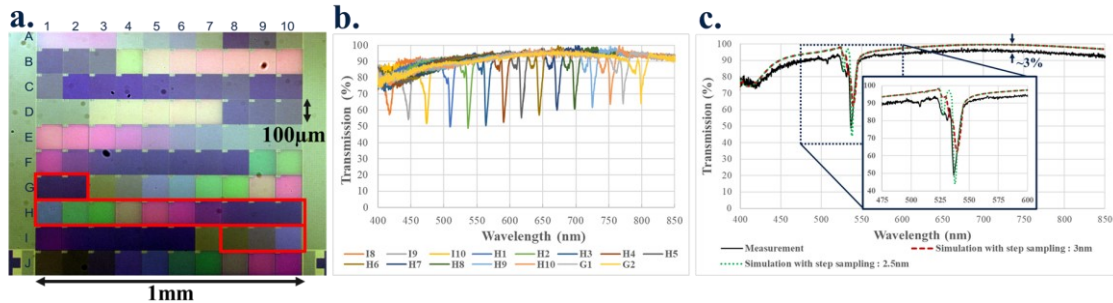


Fig. 2. a) Photography in reflection of the one-hundred-filters matrix; b) Transmission measured over 15 selected filters, those highlighted in red on a); c) Transmission of a single filter, measured and simulated with two slightly different spectral pitches.

#### 3.1. Characterization bench

The microspectrometer bench is composed of a microscope, a spectrometer working in UV-VIS-NIR, and a silicon photodetector. The sample, positioned with micrometric precision to target only one filter, is normally illuminated by a white incoherent source with a small but nonzero numerical aperture. Then a collected spot of  $20 \mu\text{m}$  is analyzed by the spectrometer, with sub-nanometer spectral resolution.

#### 3.2. Measurements

A set of 16 transmission spectra is presented Fig. 2.b, having the following grating parameters: holes depth  $70 \text{ nm}$ ,  $\text{Si}_3\text{N}_4$  guide thickness  $55 \text{ nm}$ , period  $\Lambda$  between  $220 \text{ nm}$  and  $520 \text{ nm}$ , and diameters  $D$  between  $120 \text{ nm}$  and  $460 \text{ nm}$ . Their spectral half-widths are  $5$  to  $10 \text{ nm}$ , with a dip amplitude  $-30 \%$  to  $-44 \%$  over a  $> 90\%$  baseline.

#### 3.3. Comparison with simulation

Simulations are run with Reticolo [3], a matlab program that implements the RCWA method, well adapted to low-loss periodic structures. As the glass wafer is  $210\text{-}\mu\text{m}$ -thick, it is considered as infinite and its interface with air is ignored in simulations, a feature that explains most of the  $\sim 3\%$  difference between the measured and simulated background transmission out-of-resonance, Fig. 2.c. Simulations were performed according to feature sizes measured on TEM cross-sections. The agreement is satisfying, with nevertheless an inaccuracy on  $\Lambda$  (or equivalently  $n_{\text{eff}}$ ) that we had to adjust (by a few nanometers) to achieve a perfect match of spectral dip positions. The second lobe, present in many responses such as Fig. 2.b, is well explained by including incident waves from a  $\sim 1.25^\circ$  cone, as done in both simulations Fig. 2.c. This is a plausible impact of the nonzero probe aperture [4]. Then, Fig. 2.c shows the dip depth sensitivity to spectral resolution. Even if the spectrometer precision is sub-nanometer, the probe aperture prevents achieving the expected resolution and weakens the dip.

### 4. Conclusion

We have demonstrated experimentally and by simulation a design of filters made with  $\text{Si}_3\text{N}_4$  and  $\text{SiO}_2$  2D gratings on a  $300 \text{ mm}$  glass wafer. This technology can achieve numerous narrowly filtered bands, in rejection mode, and enables a rich sampling for integrated spectroscopy applications across visible and near-infrared ranges.

### 5. References

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