Anti-Reflective All-Dielectric Metasurfaces Engraved on an Optical Waveguide Facet

Alina Karabchevsky*, **Yakov Galutin**

Electrooptical Engineering Unit, Ben-Gurion University, Israel
Ilse Katz Institute for Nanoscale Science & Technology, Ben-Gurion University, Israel
Center for Quantum Information Science and Technology, Ben-Gurion University, Israel
*corresponding author, E-mail: alinak@bgu.ac.il

Abstract

For each value of refractive index n, there exists an optimum shape of the particle that produces a minimum back-scattering together with a maximum forward scattering. This effect can be metasurface-engineered. Here we show, that randomly-distributed anti-reflective structures (RAS) have a superior anti-reflective (far-field back-scattering) properties compared to the periodic anti-reflective surfaces - both engraved on the optical waveguide facet.

1. Introduction

In our previous work [1], we investigated the scattering effect of high-index silicon nanoparticles, for which the third-order multipoles contribute considerably to the light-scattering process reported in ref. [1]. Here, we study periodic and random arrays of silicon nanoparticles of truncated conical shape engraved in a silicon rib waveguide facet. In ref. [2], we showed that the Kerker effect (i.e., the strong suppression of the back-scattering and, simultaneously, the resonant forward scattering) can be associated with the resonant excitation of a toroidal dipole moment in the system. Here, we show the metasurface-engineered suppression of back-reflection (suppression of far-field backward scattering). Figure 1a shows schematics of the silicon rib waveguide with smooth facet. Figure 1b shows the schematics of the silicon rib waveguide with periodic structure on the facet. Figure 1c shows the schematics of the silicon rib waveguide with random structure on the facet. Figure 1c shows the geometry of the unit cells which is the truncated cone.

2. Periodic metasurface

We evaluated the feasibility of studying silicon metasurface (periodic array of truncated cones) contribution to wide-band transmission in optical waveguides. Figure 2b shows the 25x2 array of periodically arranged truncated cones compared to the smooth facet shown in Figure 2a (purple). The period is Λ=463 nm and the cones are as high as h=400 nm with lower diameter of d_2=450 nm and the upper diameter d_1=290 nm as shown on Figure 2.

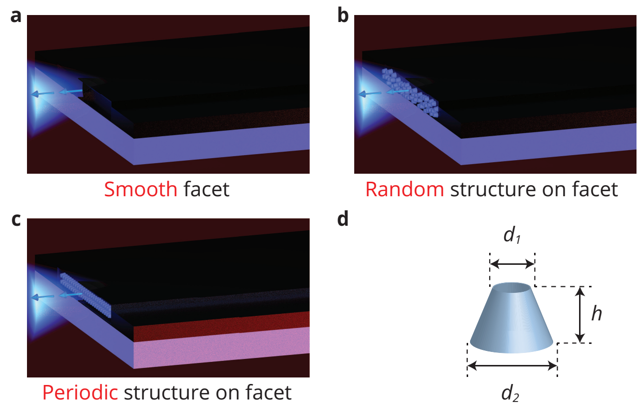

Figure 1: Render of the silicon rib waveguide with (a) smooth facet, (b) periodic metasurface engraved on the facet, (c) random metasurface engraved on the facet, (d) unit cell.

3. Engineering of random metasurfaces

To generate the spatial distribution, we set a bounded area as large as the waveguide facet and assigned randomly placed single point on it. Then we added another point, while each location is completely random within the bounded region. We excluded points if an area defined as a circle with radius d_2 around the point overlaps with an adjacent one. The process is repeated until we reach a predefined amount of points. This property is known as Poisson process in other words, there is a lack of interaction between different regions and the points in general.

4. Results and discussion

Figure 3 shows the reflection spectrum from the silicon waveguide facet. Random metasurface exhibits about 3% from 1-2 μm reflection compared to the periodic structure which exhibits about 5% and compared to the smooth surface which exhibits about 13%. Figure 3 shows the transmission spectrum of silicon waveguide. The transmission in case of the random surface is as high as about 94% while in case of the periodic structure it 91% compared to 83% in case of the smooth facet.

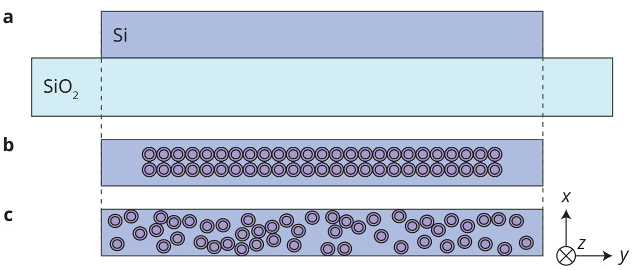

Figure 2: (a) Schematics of the silicon waveguide with smooth (purple) facet, (b) periodic metasurface on facet which includes array of 25x2 truncated cones, (c) randomly distributed 50 truncated cones.

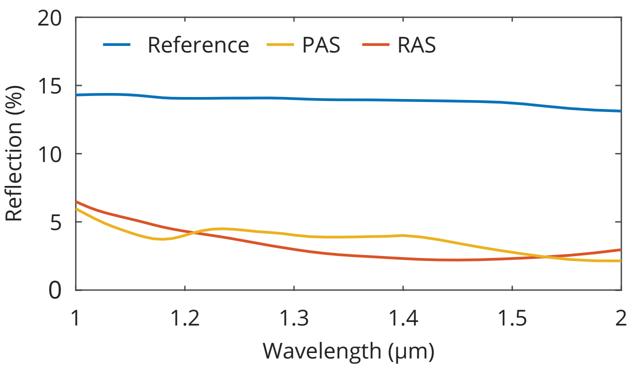

Figure 3: Calculated reflection spectrum from the facet of silicon rib waveguide with (blue) smooth facet, (orange) periodic structure on the facet and (red) random structure on the facet.

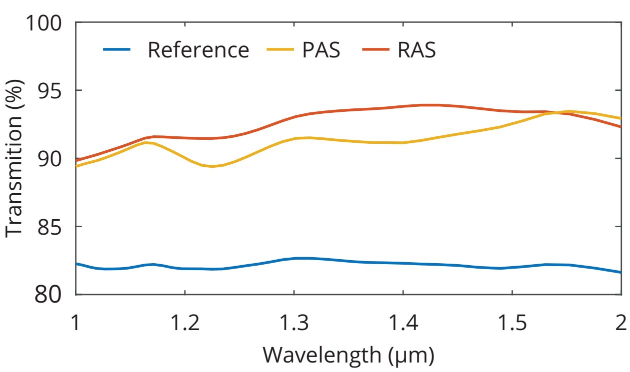

Figure 4: Calculated transmission spectrum from the facet of silicon rib waveguide with (blue) smooth facet, (orange) periodic structure on the facet and (red) random structure on the facet.

5. Conclusions

Antireflective properties of optical waveguide facet can be tuned by carefully designed metamaterial pattern engraved on the waveguide facet. We show that, random metasurfaces exhibit superior anti-reflection properties and improve the waveguide overall transmission. These textures can be directly fabricated on an optical waveguide facet and result in improved spectral transmission. The results indicate that random antireflective structures can present better performance than a periodic structure and offer great potential to applications requiring minimization of back reflections and enhanced transmission.

Acknowledgment

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References

[1] P. D. Terekhov, K. V. Baryshnikova, A. S. Shalin, A. Karabchevsky, and A. B. Evlyukhin, “Resonant forward scattering of light by high-refractive-index dielectric nanoparticles with toroidal dipole contribution,” *Optics letters*, vol. 42, no. 4, pp. 835–838, 2017.

[2] P. D. Terekhov, K. V. Baryshnikova, Y. A. Artemyev, A. Karabchevsky, A. S. Shalin, and A. B. Evlyukhin, “Multipolar response of nonspherical silicon nanoparticles in the visible and near-infrared spectral ranges,” *Physical Review B*, vol. 96, no. 3, p. 035443, 2017.