Optimized Cone-Shaped Motheye Structures for Fused Silica Glass Windows

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Abstract: We computationally varied the dimensions of cone-shaped motheye structures to optimize the transmission efficiency over a broad wavelength range. We show that optimized cone-shaped motheye structures can theoretically achieve $> 99.5\%$ transmission from 0.5 μm–2 μm.

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1. Introduction

Motheye structures are periodic biomimetic sub-wavelength structures that are inspired by the rough surfaces found on the eyes of nocturnal moths and are effective at reducing Fresnel reflections [1, 2]. In previous work, Busse et al. [3] reported optical transmission $> 99.5\%$ for wavelengths between 0.775 μm and 1.35 μm when the light is normally incident on fused silica SiO_2 glass windows with anti-reflective motheye structures on both sides. The height of the motheye cones and the gap between neighbouring cones in [3] are 0.4 μm and 0.1 μm, respectively. In our work, we show theoretically that it is possible to achieve a transmission larger than 99.5% over the wavelength range from 0.5 μm to 2.0 μm and a maximum transmission of 100% at 1.2 μm by optimizing the height of the cones and the gap between them.

2. Computational model

In Fig. 1, we show a schematic illustration of our computational model. We calculated the transmission spectra of the structured surface by simulating a planewave source normally incident on a structured sillica (SiO_2) surface using the open-source finite-difference time-domain software MEEP available under the GNU General Public License [4]. We use a spatial resolution of 5 nm for all simulations, and we take advantage of the periodicity of our system to reduce the computational grid, as is shown schematically in Fig. 1(a). The blue regions are perfectly matched layers (PMLs) that are surrounding the computational cell with a medium that in theory absorbs without any reflection electromagnetic waves at all frequencies and angles of incidence [5]. The plane surrounded by the green dash line is a planewave source that emits broadband light from 0.4 μm to 2.0 μm normally onto the motheye surface shown as the gray region in Fig. 1(a). We simulate a hexagonally packed motheye array, whose unit cell has dimensions $S_x = 1.0$ μm and $S_y = \sqrt{3}S_x = 1.732$ μm. It is sufficient to study a single polarization of the incoming light, since the results do not depend on the light's polarization when it is normally incident [6]. We calculate the transmission and reflection spectra by taking a harmonic transform of the time-domain flux through surfaces lying above and below the motheye structures.

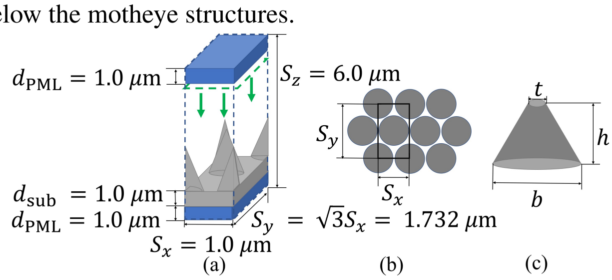

Fig. 1. Schematic view of a silica motheye structure. (a) A 3D view of the computational grid; (b) a top view showing a unit cell; (c) a side view of a truncated cone.

3. Changing the dimensions

We vary the dimensions of the truncated cones shown in Fig. 1(c) to determine the effect on the transmission spectrum. We vary each parameter of the cones independently.

3.1. Top width

In Fig. 2(a), we show the transmission spectra as we vary the top width t. As the top width increases from $t = 0.0$ to 1.0 μm, at which point the cones become touching cylinders, the transmission spectrum decreases in the entire wavelength range (0.4–2 μm) by about 2.3%. We note as well that there are wavelengths where the transmission with $t = 0.5$ μm exceeds the transmission when $t = 0.15$ μm. This result is not surprising, since resonances can occur in the periodic structures that we are considering. When $t \leq 0.1$ μm, the transmission is maximized, and its decrease in the visible region is less than 0.2%. In the limit $t = 0$, we can achieve a transmission of 100% at 1.06 μm and 1.21 μm.

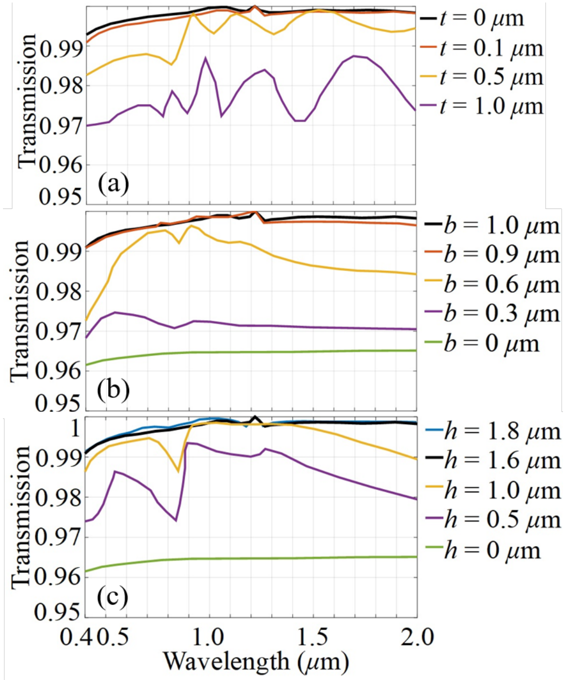

Fig. 2. Transmission spectra with varying dimensions: (a) $b = 1.0$ μm and $h = 1.6$ μm, t varies from 0 to 1.0 μm; (b) $t = 0$ and $h = 1.6$ μm, b varies from 0 to 1.0 μm; (c) $t = 0$ and $b = 1.0$ μm, h varies from 0 to 1.8 μm.

3.2. Bottom width

In Fig. 2(b), we show the transmission spectra as we vary the bottom width b. When the bottom width decreases from $b = 1.0$ μm to $b = 0$ μm, the transmission generally decreases in the entire wavelength range (0.4–2.0 μm) by about 3.5%. We observe that the transmission decreases for wavelengths below 0.7 μm and above 1.3 μm when b decreases from 1.0 μm to 0.9 μm. However, the resonant maxima shift to shorter wavelengths, leading to an increase in the transmission at some wavelengths. In general, the peaks of the resonant maxima decrease as b decreases.

3.3. Height

In Fig. 2(c), we show the transmission spectra as we vary the cone height h. The resonant maxima shift to longer wavelengths as we increase h and the peaks of the resonant maxima and the general transmission spectra also increase. There is little improvement in the transmission spectrum when $h > 1.6$ μm, although the transmission minima occur at different wavelengths because the locations of the resonant minima shift.

4. Conclusion

We theoretically studied the transmission of cone-shaped motheye structures in the range 0.4–2.0 μm with normal light incidence. We varied the dimensions of the motheye structures, and we showed that we could achieve nearly 99.5% transmission over the entire wavelength range of $0.5 - 2.0$ μm. Our results demonstrate that transmission in this wavelength range is optimized by making the cones sharper, minimizing the gap between neighbouring cones, and using heights of 1.6 μm or more.

References

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