Photonic Bandgap Materials with Disorder

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Abstract

Structured dielectric materials in three dimensions can exhibit photonic properties that allow control of the propagation of light. For crystalline structures, a complete or incomplete photonic bandgap emerges and the propagation of light is hindered or even completely suppressed over a certain range of wavelengths. Full photonic bandgaps open up for dielectric materials with a sufficiently high refractive index contrast. Embedding defect sites in an otherwise perfect crystalline lattice such as a woodpile photonic crystal allows for the appearance of defect states in the bandgap and for the trapping of light in three dimensions. Interestingly, it appears that many of these unique properties are not tied exclusively to crystalline structures. In a recent numerical study Florescu et al. demonstrated that particular designer disordered materials could display large, complete photonic bandgaps in two dimensions [1]. Mapping hyperuniform point patterns with short-range geometric order into tessellations allows the design of interconnected networks that give rise to enhanced photonic properties.

Here we present experimental results for the fabrication of ordered and disordered photonic structures made from high refractive index materials such as TiO_2 and silicon [2-5]. First, the structures were fabricated via direct laser writing in polymer by adapting the standard writing protocol presented in [2]. A substantial increase in the material refractive index is necessary to observe a photonic gap. To this end we employ ZnO and TiO_2 infiltration [3-5] combined with the well-established silicon double inversion method [5]. This multi-step replication technique consists of successive infiltration and etching processes. The high quality of the resulting structures is illustrated by focused ion beam etching coupled to a scanning electron microscopy images as well as a pronounced and angular independent transmittance dip in the spectral response, measured by Fourier Transform Infrared spectroscopy [3,6]. Moreover we study experimentally and numerically the influence of random and correlated defects in periodic woodpile structures and the role of short-range order and hyperuniformity in the formation and robustness of bandgaps.

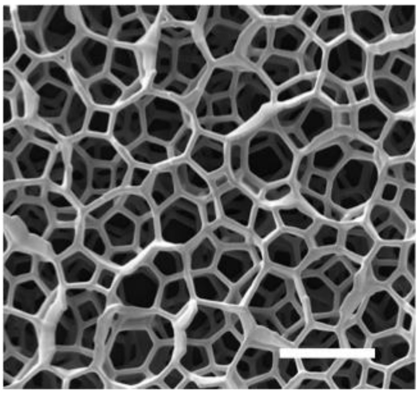

Figure: Top view scanning electron micrograph of a hyperuniform photonic network fabricated by direct laser writing in a polymer photoresist [2]. Scale bar 5 µm.

References

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