Electromagnetic Wave Interaction with Disordered Bicontinuous Interfacially Jammed Emulsion Gels

Dimitrios C. Tzarouchis (1), Tiancheng Wang(2), Daeyeon Lee(2), Nader Engheta(1), and Kathleen Stebe(2)
(1) Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania 19104; e-mail: dtz@seas.upenn.edu, engheta@seas.upenn.edu;
(2) Department of Chemical and Biomolecular Engineering, University of Pennsylvania, Philadelphia, Pennsylvania 19104; e-mail: wtianc@seas.upenn.edu, daeyeon@seas.upenn.edu, kstebe@seas.upenn.edu;

Photonic disordered media are emerging material platforms with promising potentials where the disorder may be harnessed for the next generation of photonic light management (control, storage, etc.) [1]. A recently discovered unique class of disordered media called bicontinuous interfacially jammed emulsion gels, or bijels (Fig.1 A), has opened new avenues for media with multiple length scales and material compositions and their potential usage in the visible-mid infrared domain [2]. In this work, we study the electromagnetic properties of bijels for artificially engineered material/metamaterials applications by performing a series of numerical electromagnetic simulations and then comparing them with experimental measurements. Moreover, we explore the usage of bijels for photonic applications.

One of the central challenges for electromagnetic modeling of bijels is that these structures comprise distinct components with a broad range of length scales. For example, a typical bijel slab consists of connected polymer (PMMA) regions with a feature size of approximately 1um. At the same time, a thin layer (approx. 200nm) of nanoparticles, such as SiO_2, resides on each interface. To incorporate these disordered refractive index profiles, we adopt a Gaussian random field (GRF) mathematical model that captures the main geometrical features of these composites (Fig.1 B.). In particular, the generating structure factor reads

$$S(\boldsymbol{r}) = \sqrt{\frac{2}{N}} \sum_{i=1}^{N} \cos(\boldsymbol{k}_i \boldsymbol{r} + \varphi_i)$$

where $\boldsymbol{k_i} = \frac{2\pi}{d} \boldsymbol{r_i}$ is the characteristic size wavevector, $\boldsymbol{r}_i$ is a randomly oriented unit vector in the k-space, d is the feature size, and φ_i is a random phase. Typically, the bijel structure can be emulated with $N=10^4$ [3]. In this work, we explore how the GRF model can help us understand the resonant behavior of bijels compared to other effective medium theories and test the applicability of the GRF for predicting the structure's material parameters.

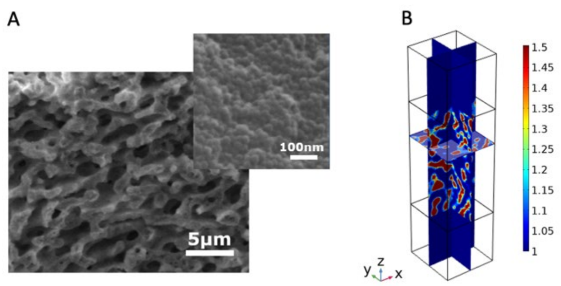

Figure 1. (A) SEM pictures of a bijels and (B) the refractive index distribution generated by a three-dimensional (3D) GRF model of a bijel slab with thickness 10 um, with 1 um feature size and volume fraction 0.35-0.15 for PMMA and SiO_2, respectively.

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References

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