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In their recent letter, Jen et al.1 present an observation of a negative real refractive index over a broad bandwidth of almost entire visible spectrum. They demonstrate a fabrication of randomly distributed silver/silicon dioxide/silver nano-sandwiches grown by an oblique angle deposition technique. The authors calculate the equivalent constitutive parameters of the corresponding single-functional-layer nano-sandwich film and determine negative refractive index for normally incident light.

The paper, however, misleads the reader about the accuracy of the concluded equivalent negative refractive index presented in Fig. 2 of their paper. Jen et al. arrive their conclusion by using the bianisotropic retrieval procedure described in Ref. 2.

The refractive index \( n \) using the bianisotropic retrieval procedure is obtained from the expression

\[
\cos(nkd) = \frac{s_{21}}{2} \times \left[ \frac{1 - \frac{1}{z_+}}{1 + s_{11} - (1 - s_{11}) \frac{1}{z_1}} + \frac{1 - \frac{1}{z_-}}{1 + s_{11} - (1 - s_{11}) \frac{1}{z_1}} \right], \tag{1}
\]

where \( s_{11} \) and \( s_{21} \) are the reflection and transmission coefficients, respectively, for the propagation in the +z-direction in Fig. 3 of Ref. 2. \( z_+ \) and \( z_- \) are effective or equivalent material impedances for the propagations in the +z- and –z-directions, respectively. \( z_1 \) is the relative impedance of the isotropic material #1 in Fig. 3 of Ref. 2. \( k \) and \( d \) are free-space wave number and bianisotropic slab thickness, respectively.

Equation (1) gives infinite number of solutions for \( Re(n) \). It is ambiguous to choose the correct physical branch. The ambiguity may be resolved in the same fashion as the isotropic retrieval procedure by comparing the multiple unit cell retrieval results.3,4 The retrieved \( Re(n) \), especially for the subwavelength structures with different numbers of unit cells, should yield reasonably consistent or converging values for the refractive index (i.e., length-independence). If the structure, like in the paper of Jen et al., is not sufficiently sub wavelength and has only a single functional layer, we cannot assign the structure a unique value for the equivalent refractive index using the retrieval procedure and therefore the ambiguity remains.

The diameters of the fabricated nano-sandwiches proposed by Jen et al. have a Gaussian distribution which centers at 215 nm. In Fig. 1, we show the retrieved equivalent refractive index for the nano-sandwich structures with 200 nm diameters. Silver is described by the Drude model with the bulk plasma frequency \( f_p = 2180 \text{THz} \) and the collision frequency \( f_c = 13.5 \text{THz} \). We used the same geometric parameters in Ref. 1 for the other parameters. We performed the simulations using commercially available finite integration algorithm based CST software.

Despite a single non-negative branch for the \( Im(n) \) (shown blue in Fig. 1), the \( Re(n) \) has multiple mathematical solutions shown by different branches in Fig. 1. Clearly, there are mathematically both negative and positive index solutions. Reference 1 does not provide sufficient physical evidence to determine which branch should be chosen for the \( Re(n) \). Therefore, the negative index claimed by the authors is questionable.

Although we used periodic boundary conditions in our simulations, the essential point of this comment letter (i.e., multiple solutions) can be easily grasped in Fig. 1. The plots for randomly distributed nano-sandwiches should be qualitatively similar to Fig. 1 except that flatter dispersion and shifts in frequencies due to different geometric parameters should be observed.

![FIG. 1. Retrieved equivalent refractive index for a single-layer nano-sandwiches with 200 nm diameters. Other parameters are given in Ref. 1. Each branch \( m \) corresponds to a different mathematical solution.](image-url)
The ambiguity may be normally resolved by retrieving the equivalent refractive index for multiple layers of nano-sandwiches. Fig. 2 shows the retrieved equivalent index of refraction for one (dots), two (circles), and three (crosses) layers of nano-sandwiches in the direction of propagation. The simulation assumes each layer is geometrically identical and separated by 100 nm. The regions indicated by the boxes are those where the retrieval procedure for different number of layers consistently yields reasonably close values for $\text{Re}(n)$.

Given the randomness in the fabricated structures in Ref. 1, more numerical and experimental works are needed to prove any consistent behavior in the equivalent refractive index as outlined in Fig. 2. Because it will be difficult to fabricate multi-layer nano-sandwiches, we suggest Jen et al. to retrieve the equivalent parameters from the simulated nano-sandwiches with multiple layers which are weakly coupled (i.e., sufficiently separated) and have identical geometries directly extracted from the scanning electron micrographs of the fabricated structures.

By responding to our comment, Jen et al. may clarify the accuracy of the retrieved equivalent negative index of refraction extending through almost entire visible spectrum. This clarification is particularly important; because the retrieval procedure has been widely used for a decade by the communities of metamaterials and negative-index materials.

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