Multiport power divider based on index near zero metamaterial

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Among the fertile possibilities brought by the metamaterials, the zero index of refraction materials (ZIMs) are very interesting fields of research [1, 2]. One of the most fascinating features of the ZIMs is that the non-vanishing field in ZIMs should be spatially constant [1]: when a light wave is normally incident on a surface of ZIM, it will be coupled to the spatially constant field in the ZIM whose phase will be matched with that of the incident field at the surface. However, for any incident angles other than zero, the field will be totally reflected [1]. Interestingly enough, such properties of ZIMs can be implemented by the materials having nearly zero permittivities [3-5], and several devices such as subwavelength transmission channel [3], sharp bends and corners [6], and integrated circuits [7] have been reported.

In this work, we will show by numerical methods that the ZIMs can be used as multiport power divider. We illustrate an example of power divider system in Fig. 1(a). In this system, we use two-dimensional plasmonic slab waveguides for input and output channel which have metal cladding and conventional dielectric core. Without loss of generality, we assumed that the metals are lossy which have the relative permittivity of -10-0.6*i* at the operation wavelength and the core dielectrics are air. Following the literature [3], the key requirement of the transmission through ZIM channel is that the dimension of the waveguide is electrically small. In this simulation, the widths of all waveguides are assumed as $\lambda_0 / 5$ where λ_0 is the free-space wavelength. To model the nearly zero index metamaterial, we assumed that the relative permittivity of the material is -0.001-0.001*i* while the relative permeability is 1. The incident field is assumed TM-polarized.

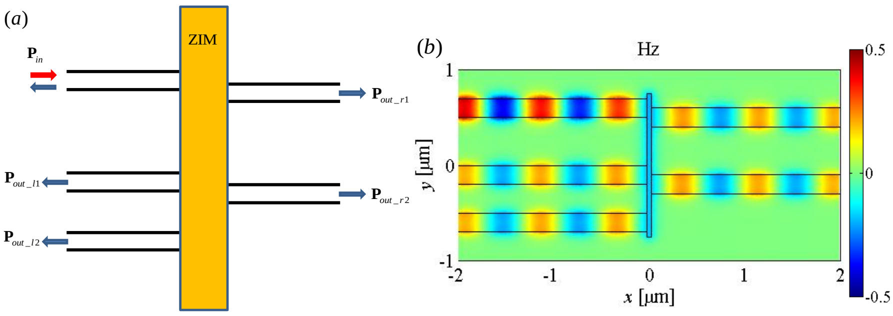

Fig. 1. (a) Schematic diagram of multiport power divider. (b) Numerical result.

As shown in Fig. 1(b), the electromagnetic field fed from the uppermost waveguide is divided by the thin ZIM layer of which width is $0.05\lambda_0$ and transmitted through the output ports. Note that the positions of the output ports are placed in a random manner and even the power couplings into the backward directional waveguides are qualitatively the same as those of forward ones. In our simulation, the existence of loss in the metallic walls and the ZIM itself makes slight phase retardations in each output ports. However, as one can see in Fig. 1(b), the phase deviation and the differences in the output power are quite small. In our result, the standard deviations of the output phase and normalized output power are 0.054 radian and 0.034 dB, respectively.

We further consider more feasible condition that the ZIM layer is composed with alternating stack of materials having the relative permittivity of positive (air in this case) and negative (-1-0.001*i*) values. The numerical result is depicted in Fig. 2(a). As shown in Fig. 2(a), the ZIM layer composed by stack of non-ZIM materials exhibits similar functionality. However, the imperfection of the ZIM layer affects the equality in phase and the power distributions and results in observable phase difference. For example, the uppermost waveguide at the right side of ZIM layer shows significantly different feature compared with other ones. However, the result still shows that the ZIM power dividing can be effective and robust.

More interestingly, if the canceling of the effective index by composition of the materials is applied only in one direction as in Fig. 2(b), more functional feature can exist. In this figure, the alternative stacking of positive and negative materials is applied only in *y*-direction and not in *x*-direction. As a result, the effective zero index characteristics are implemented only in vertical (*y*-) direction. Therefore, only the backward-directional power couplings are achieved.

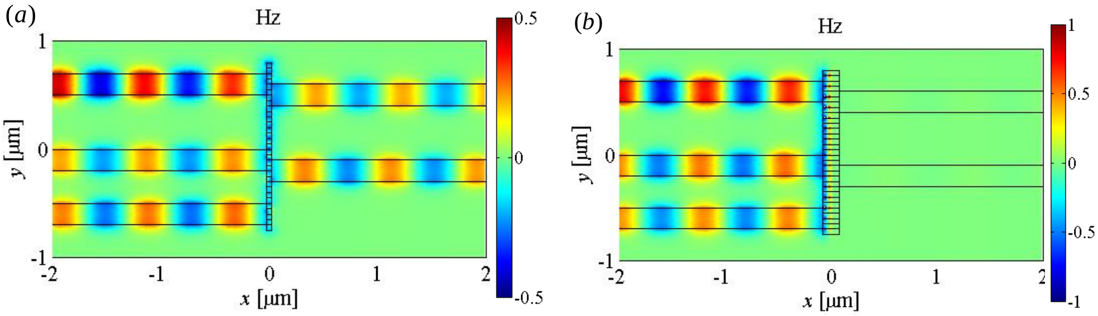

Fig. 2. Multiport power divider made by composite metamaterials. The width of ZIM layer is (a) $0.05\lambda_0$ and (b) $0.15\lambda_0$.

As we have shown, we propose that the ZIMs can be used as a compact joint for the multiport power divider. We also showed that the composed metamaterials can show similar functionality with ideal case. In addition, with an illustrative example, by selecting the way of composing ZIMs, the functional performance of the power divider can be modified. We hope that our study will be helpful in designing and utilizing novel devices based on ZIMs.

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