Propagation of waves in a composite of overdense plasma and metamaterial studied by numerical simulations

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1. Background

Regulation of wave propagation by using plasmas has been studied (e.g. plasma photonic crystals [1] and plasma antennas [2]) since plasmas have controllable permittivity ε and ability of quick switching by regulating external discharge current. Plasmas can only tune ε though refractive index N is determined by both ε and permeability μ. Our group has combined a overdense plasma with double-split-ring resonators (DSRRs, one of negative-μ metamaterials) experimentally [3] to realize a negative N state which improves controllability of waves; however, the propagation of waves has never been clarified. We performed electromagnetic particle simulations and FDTD simulations in cases with plasmas and metamaterials [4], and we show the extraordinary propagation of waves in this report.

2. Simulation model and method

We use the electromagnetic particle code modified from KEMPO1 [5] to introduce metamaterial effects [4]. Figure 1 shows the one-dimensional simulation model [4]. The sinusoidal external current along z axis (x = -12.8) radiates the TEM wave. We set electrons, heavy ions, and the imaginary magnetic current J_{m} along y axis in $0 < x < 12.8$ to simulate a overdense plasma and metamaterials, respectively, where J_{m} obeys the dispersive equation $J_{\mathrm{m}} = \omega^2{}_{\mathrm{m}}B_y$ and ω_{m} is the magnetic resonance frequency. Since the plasma frequency ω_{p} and ω_{m} are set as follows; $\omega_{\mathrm{p}}/\omega_0 = 1.7$ and $\omega_{\mathrm{m}}/\omega_0 = 1.5$, ε of the plasma and μ of the metamaterial are negative.

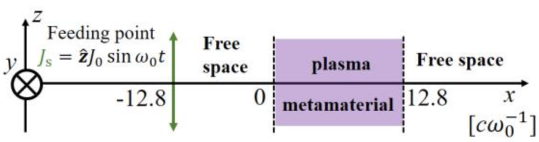

Figure 1: One-dimensional simulation model. Plasma and metamaterial exist in $0 < x < 12.8$.

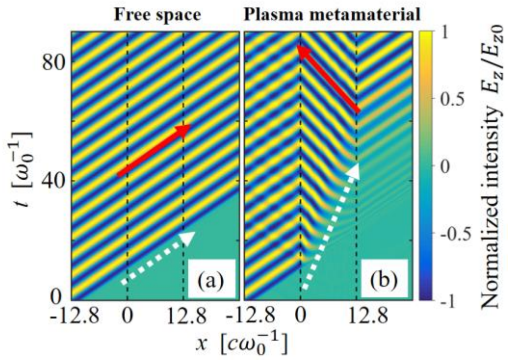

Figure 2: Time development of transverse electric field E_z in cases of (a) free space and (b) a plasma-metamaterial composite. Slopes of dotted and solid arrows are velocities of energy and phase, respectively.

3. Simulation results

Figure 2 shows propagation of waves in (a) free space and (b) the composite of the overdense plasma and the negative-μ metamaterial [4]. In comparison with Fig. 2(a), Fig. 2(b) shows opposite directional equiphase lines in $0 < x < 12.8$. The composite works as a negative N material because the direction of the electromagnetic energy flow (dotted arrow) is opposite to that of the phase velocity of waves (solid arrow) in Fig. 2(b). We have the plan to report results of two-dimensional FDTD simulations of the composite.

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