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プラズマ・メタマテリアルによる機能性電磁波媒質の実現
Plasma Metamaterials: Functional Media for Electromagnetic Waves

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Metamaterials, whose concept was proposed about 10 years ago, exhibit extraordinary properties by their spatially periodic micro structure; the properties such as perfect lens and cloaking [1, 2] cannot be achieved using conventional bulk materials with good microscopic homogeneity. When we make composites of plasmas and such metamaterials that are usually made of metallic and/or dielectric materials, we can expect further functions which are beyond conventional materials, plasmas themselves, and the ordinary metamaterials, and we call them “plasma metamaterials” hereafter [3], as shown in Fig. 1 as a conceptual view.

In the plasma metamaterials, embedded plasmas play several important roles. First, tunability of on/off states is significant in comparison with other solid-state materials, and a pattern inside an array of microplasmas is variable. This indicates that we can obtain materials with variable lattice constant. In addition to this simple feature, we can mention further advantages of plasma metamaterials as described below.

For instance, dielectric constant is quite unique in comparison with other materials. Non-magnetized plasmas have complex permittivity ε whose real part is both positive and negative and whose imaginary part is adjustable. The electron plasma frequency depends on electron density that varies with input electric power, and the resultant change in $\mathrm{Re}(\varepsilon)$ leads to phase shift of propagating waves and to achievement of a negative permittivity state, which is favorable in metamaterials with negative refractive index. The electron elastic collision frequency is functions of gas species and pressure, and the resultant change in $\mathrm{Im}(\varepsilon)$ affects attenuation of the waves.

Another highly potential feature of the embedded plasmas is nonlinearity. As mentioned earlier, the electron plasma frequency is a key factor for ε and depends on electron density. Electron density is as a function of electric fields for plasma generation; ionization coefficient has a nonlinear function on reduced electric fields. That is, plasmas are fairly nonlinear, and many kinds of such researches as nonlinear wave propagation have been studied so far. Nowadays nonlinear metamaterials have attracted significant attention, and plasmas are very suitable for this role.

Briefly, we summarized our recent relevant

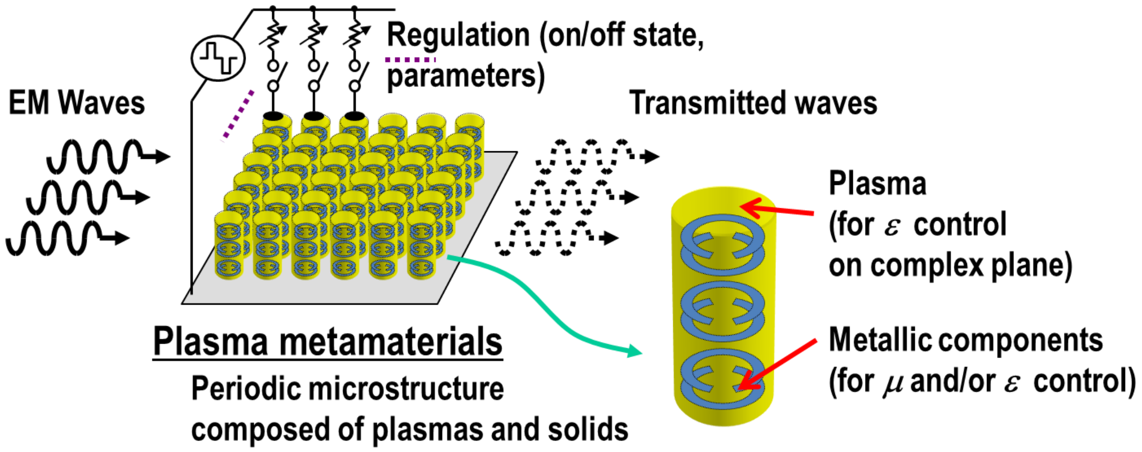

Figure 1. Conceptual view of plasma metamaterials.

studies in the following. We verified several schemes of plasma metamaterials in experiments, including dynamic negative-refractive-index materials [4, 5], tunable supporters for spoof surface plasmon polaritons [6], and chain-like structures of localized-surface-plasmon-like modes [7, 8] as well as simple plasma photonic crystals [7, 9, 10]. Recently, we predicted saddle-node bifurcation of nonlinear plasma metamaterials with negative permeability μ [11]. Our recent studies also include identification of a “defect” effect on metamaterial functions and its application to imaging of dielectric constant for detection of irregular tissues for medical application [12].

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