# Metamaterials for Wireless Generation of Microplasma Array

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**Abstract**- Here, we present a novel application of metamaterials for remote generation of plasma, the fourth state of matter. One of the most interesting property of the metamaterials, the sub-wavelength localization of incident electromagnetic wave energy, is employed for the generation of high electric field to ignite and sustain microwave plasmas. The two-dimensional array of microplasma is generated using metamaterials. Frequency selective generation of microplasma in a large array is made possible by employing metamaterial units each with different resonance frequencies.

A novel application of metamaterials for remote generation of microplasma at microwave frequency is demonstrated. Microwaves have been used to generate non-thermal or cold plasmas [1]. Microplasma is defined as plasma when one or more of its dimensions are less than a millimeter in size. Metamaterials provides a advantage of sub-wavelength localization of incident microwave energy, which has the potential to generate high electric field that can be used to ignite and sustain microplasmas in the surrounding gas medium. An array of resonators in a metamaterial can generate a two-dimensional array of microplasmas. Microwave energy can be coupled wirelessly and remotely to the metamaterials (see Fig. 1). This can be done using a patch antenna for transmitting microwave power wirelessly to the metamaterial array. The frequency selective nature of metamaterial unit cells makes it possible to couple microwave energy only to unit cells at resonance, in order to generate spatially localized microplasma using multiple resonators with different resonance frequencies. A dual frequency metamaterials is implemented with resonance frequencies at 2.1 GHz and 2.45 GHz to demonstrate such frequency selectivity. As shown in Fig. 2, higher electric field appears in larger resonators when metamaterial is excited with 2.1 GHz, and similarly in a smaller resonator when excited with 2.45 GHz. Figure 3 shows measured and simulated resonance frequency of metamaterials. Plasma generation experiment is carried out in argon environment at pressure of 40 Torr. As shown in Fig. 4, the microplasma is generated in a gap of larger resonators when excited with 2.1 GHz microwave as expected. Similarly, microplasma is generated in smaller resonators when excited with 2.45 GHz. In conclusion, we have shown that metamaterials can be utilized for frequency selective spatially patterned generation of microplasmas. Also, microplasma can be generated remotely and wirelessly over large area. The electron density in the microplasma is in the range of $10^{12}$-$10^{14}$ $cm^{-3}$ at atmospheric pressures. Such microplasma arrays exhibit nonlinear behavior [2]. They provide a fundamentally new material system for future investigations in novel applications, e.g. nonlinear metamaterials. Moreover the high electron density plasma provides a unique electronic material system with possibly novel functions.

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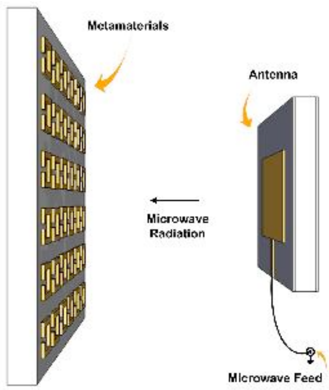


Fig. 1. Metamaterials for remote generation of microplasma array. Patch antenna couples microwave energy to metamaterial array.

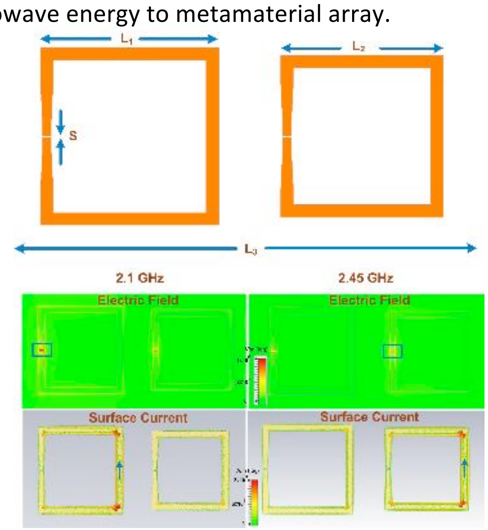


Fig. 2. Dual frequency metamaterials for the frequency selective generation of the microplasma array, one at 2.1 GHz and other at 2.45GHz.

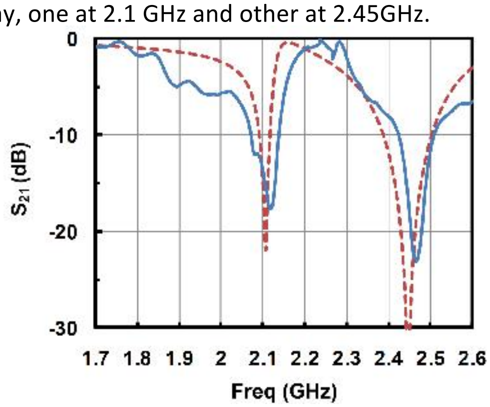


Fig. 3. Simulated (dotted line) and measured S-parameter response of dual frequency metamaterials.

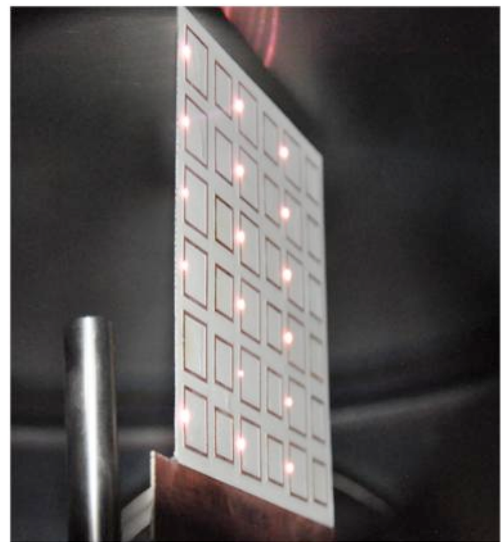

Fig. 4. Remote generation of microplasma array at 2.1 GHz in dual frequency metamaterials.

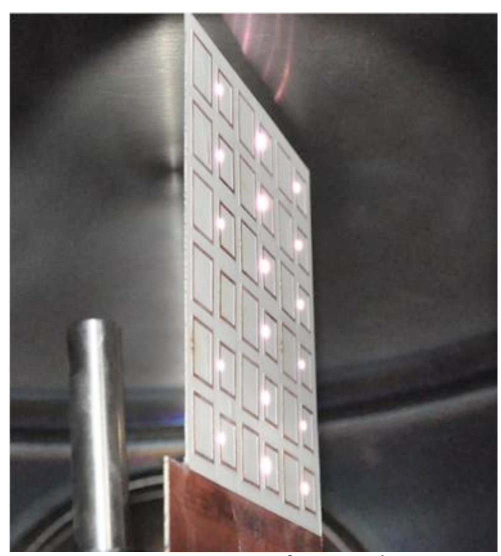

Fig. 5. Remote generation of microplasma array at 2.45 GHz in dual frequency metamaterials.