Effects of double-split-ring resonators to plasma local behavior powered by microwaves

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1. Background

Plasmas have been studied as optical nonlinear media because of their complex kinetic motions. A plasma sheath is one source of nonlinearity since it includes a rectification factor which induces a nonlinear current. Our group has studied the generation of plasmas by microwaves with double-split-ring resonators (DSRRs) which are typical metamaterials whose permeability μ becomes negative. We have tried to efficient energy injection of microwaves into overdense plasmas by using DSRRs since negative permittivity ε of overdense plasmas can be cancelled by negative μ. We reported the enhanced generation of harmonic waves [1] and explained it by the nonlinear coupling model between DSRRs and plasmas [2]. In this report, we show microscopic effects of DSRRs' resonance for the generation of plasmas.

2. Experimental setup

Figure 1 shows our experimental setup. 2.45-GHz microwaves enter the vacuum chamber filed with 100-Pa Ar gas via the waveguide (WR-430). DSRRs whose μ is -2.6-0.3j for 2.45 GHz installed in the waveguide to induce the magnetic resonance. We performed the probe measurement at positions P1 and P2 in Fig. 1, which are close to the back and the resonance-pattern-printed sides, respectively.

3. Experimental results

Figure 2 shows monitored electron currents as a function of bias voltage. We draw lines to estimate electron temperature and plasma potential. Though estimated plasma potential shows the same level in both positions, estimated electron temperature at position P2 (the slope of lines on red symbols) becomes clearly higher than that at position P1. Electron current at position P2 is greater than that at position P1 in every bias-voltage case. These results suggest that the plasma at position P2 becomes more energetic than that at position P1 because of the magnetic resonance of DSRRs, which is another effects of DSRRs (the other is negative μ).

Reference [1] A. Iwai, Y. Nakamura and O. Sakai, Phys. Rev. E, **92** (2015) 033105. [2] Akinori Iwai, Yoshihiro Nakamura, Alexandre Bambina, and Osamu Sakai, Appl. Phys. Express, 8 (2015) 056201.

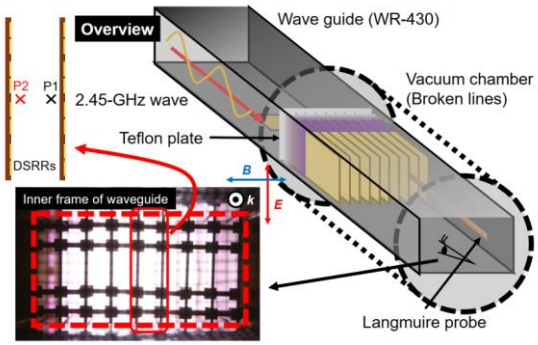

Figure 1: Experimental setup. Positions P1 and P2 are close to the back and the pattern printed sides, respectively.

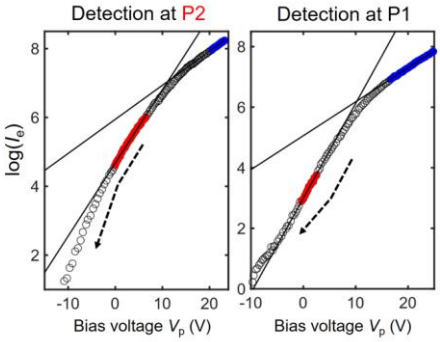

Figure 2: Electron current as a function of bias voltage to Langmuire probe.