Experimental and Numerical Analysis of Plasmonic Local Heat Loaded with Metamaterial Perfect Absorber

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Plasmonic local heating induced by localized surface plasmon (LSP) is attracting the attention of many researchers as a nanoscale energy source. Our group has developed and demonstrated the plasmonic photo-thermoelectric device driven by a combination of plasmonic local heating and thermoelectric conversion (Fig. 1(a)) [1]. The output power of a plasmonic photo-thermoelectric device will be proportional to the amount of plasmonic local heat temperature. Therefore, the plasmonic structure, a light receiver of the device, which generates a higher temperature is required for improving the conversion efficiency of the device. In this research, we adapted the metamaterial perfect absorber (MPA) to the plasmonic photo-thermoelectric device as the light receiver instead of the Ag nanorod (Ag NR) array. MPA consists of Ag NRs and thin film (Fig. 1(b)) sandwiching a poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) thin film as a dielectric spacer. When the MPA is illuminated with the light, the strong magnetic field confinement is induced at the PEDOT:PSS layer by the quadrupole mode, resulting in perfect light absorption. MPA is expected to generate larger plasmonic local heat compared to the Ag NRs. In fact, loading the MPAs to the device instead of the Ag NRs enhanced the absorptivity and the external quantum efficiency (EQE) of the device by 2.9 and 2.7 times, respectively (Fig. 1(c)). The reason for the improvement in the EQE is considered that the quantity of the plasmonic local heat was increased owing to the light absorption enhancement, leading to the larger temperature gradient across the thermoelectric conversion layer. In order to verify the improvement in the EQE and the increase of local heat quantitatively, we calculated and compared the local heat temperatures generated at the Ag NRs and the MPAs experimentally and numerically.

In the experimental method, the thermoelectric simulation was used to estimate the local heat temperature generated at the Ag NRs and the MPAs. The model took the experimental values of the photocurrent and the Seebeck coefficient. As a result, the estimated temperature was 8.83 K for the Ag NRs and 22.77 K for the MPA. In the numerical method, the generated temperature was calculated based on the electromagnetic field simulated by finite element method, since the amount of plasmonic local heat is proportional to the electric field intensity. The temperatures of the Ag NRs and the MPAs numerically estimated were 8.87 and 19.31 K, respectively. The difference between the temperatures estimated by experimentally and numerically was 0.4% for the Ag NRs and 17.9% for the MPAs. This result indicates that the local heat temperature estimated experimentally is at an equivalent level to the one estimated numerically. Therefore, we concluded that the improvement in conversion efficiency was realized by increasing the amount of the local heat temperature acquired by the MPA [2].

Reference

[1] W. Kubo, M. Kondo, and K. Miwa, *J. Phys. Chem. C*, **123**, 35, 21670-21675 (2019).
[2] M. Horikawa, X. Fang, and W. Kubo, submitted.

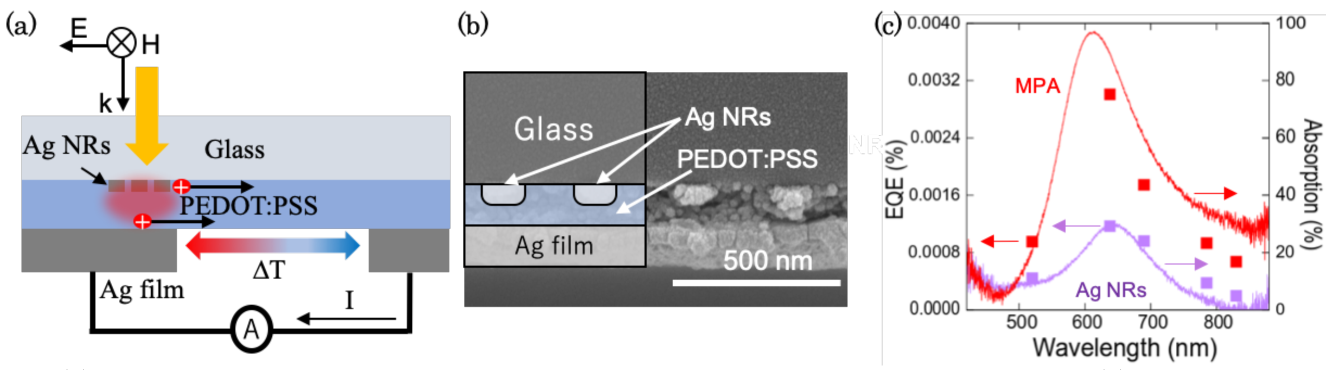

Fig. 1(a) Schematic of the plasmonic photo-thermoelectric device loaded with the MPA, **(b)** cross-sectional SEM image of the MPA configuration, and **(c)** comparison of the absorption spectra (solid lines) with the EQEs of the devices loaded with the Ag NRs (red plots) and the MPA (purple plots).