# Plasmonic Local Heat Amount Contributed to Photo-thermoelectric Conversion

Kaito Miwa and Wakana Kubo

Tokyo University of Agriculture and Technology (TUAT)
E-mail: w-kubo@cc.tuat.ac.jp

Hot electrons whose energies are higher than those thermally excited are generated in a metal nanostructure behind the localized surface plasmon excitation, leading to the generation of plasmonic local heat via electron-phonon relaxations. The amount of local heat is enough powerful to produce photo-thermal reactions. Therefore, we came up with the idea to apply the plasmon local heat energy to photoelectric conversion and photodetection driven by thermoelectric conversion triggered by local heating [1]. In order to realize this photodetection mechanism, we developed a photodetector consisting of Ag film and nanohole (Ag NH) array that generate local heat through localized surface plasmon. Light illumination on the Ag NHs generates plasmonic local heating, resulting in a temperature gradient across the Ag film. The photocurrent of the device is induced by the Seebeck voltage based on the temperature gradient [2]. Therefore, a larger amount of plasmonic local heat generated at the Ag NHs leads to an increase of the device sensitivity. Thus, it is necessary to know the amount of local heat by experimentally and theoretically, leading to a device guideline for the better photodetector. In this research, we estimated the amount of plasmonic local heat generated at Ag NH experimentally and numerically.

NH arrays were formed on a positive resist layer on a glass substrate by electron beam lithography, and a 40 nm of Ag film was deposited on the resist layer by vacuum evaporation (Fig. 1(a)). The reflection spectrum showed the plasmon resonance wavelength of the Ag NHs at 670 nm. Light illumination with 690 nm on the Ag NHs generated the electric current of 173 nA flowing in the Ag nanofilm due to thermoelectric conversion. The wavelength dependences of the photocurrents of the Ag nanoholes were examined (Fig. 1(b)). The wavelength dependence of the photocurrents for illumination of the NHs followed a similar trend to the wavelength dependence of the NH extinction spectra. These results suggest that light illumination on the NHs excites surface plasmon polaritons, leading to plasmonic local heating as a consequence of plasmon loss. Heat transfer simulation revealed that the temperature of the illumination spot was 4.61 K, which induces an electric current of 173 nA flowing in the silver film.

In order to verify the estimated heat amount, we calculated the plasmonic local heat amount numerically using finite element method (FEM). The plasmon resonance wavelength of Ag NHs obtained by FEM was 669 nm. The strong electric fields at 669 nm were localized at the Ag film edges and the disk (Fig. 1(c)). Since the plasmonic local heat amount is proportional to the electric field intensity (Eq. 1), we estimated the amount of plasmonic heat using the Eq. 1,

$$q(\mathbf{r}) = (\omega/2)\mathrm{Im}\big(\varepsilon(\omega)\big)\varepsilon_0|\mathbf{E}(\mathbf{r})|^2 \quad \text{Eq. 1}$$

where $\varepsilon_0$ is the vacuum permittivity, $\varepsilon(\omega)$ is the relative permittivity of the material, and $|\mathbf{E}(\mathbf{r})|^2$ is the intensity of the electric field. Plasmonic local heat amount can be affected by the accumulation effects of NHs, therefore we need to calculate the plasmonic heat amount produced upon changing the unit numbers of NHs in order to estimate accurate amount of the heat contributed to the photocurrent. Consequently, the amount of plasmonic heat generated on the illumination spot was 11.0 K, which was 2.39 times higher than that estimated experimentally. There is a difference between the temperatures estimated experimentally and numerically; however, this calculation method used in this research is valid for estimating plasmonic local heat amount, and will facilitate optimization of configurations for plasmonic local heating.

**References**

[1] W. Kubo, M. Kondo, and K. Miwa, *J. Phys. Chem. C* (2019) **123**, 21670
[2] K. Miwa, H. Ebihara, X. Fang, and W. Kubo, *Appl. Sci* (2020) **10**, 2681

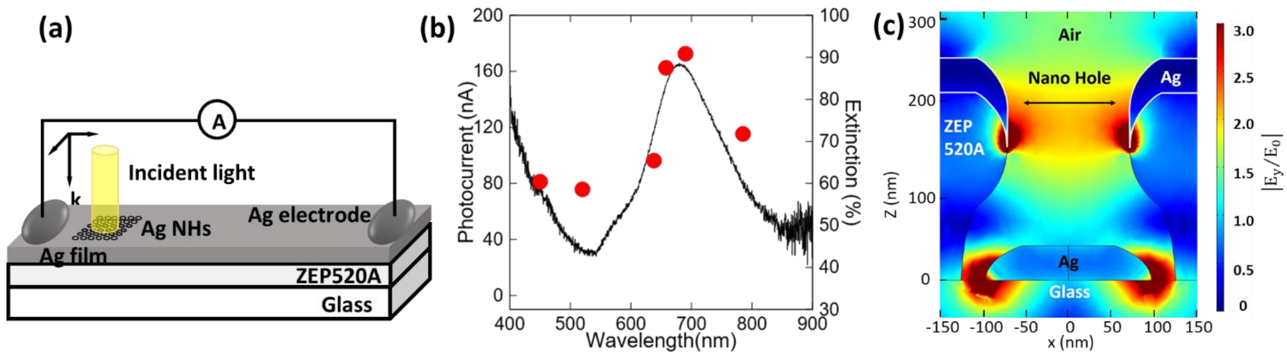


Fig. 1(a) Schematic of plasmonic photo-thermoelectric device, (b) comparison of the measured extinction spectrum of the NHs with the photocurrents of the plasmonic photo-thermoelectric conversion with light illumination on the Ag NHs, (c) cross-sectional electric field distribution of the NHs at plasmon excitation wavelength (669 nm).