

Metamaterial thermoelectric conversion

Wakana KUBO

Division of Advanced Electrical and Electronics Engineering,
Tokyo University of Agriculture and Technology, 2-24-16 Naka-cho, Koganei-shi, Tokyo 184-8588, Japan
E-mail: w-kubo@cc.tuat.ac.jp

To increase the efficiency of energy harvesting, technologies that can utilize weak thermal energies existing in environments are in demand; however, conventional technologies fail to realize this objective because energy accumulation does not occur in them. Herein we propose a metamaterial thermal engineering technique by which thermal energy can be accumulated from the surrounding environment and can be converted into electricity.

The thermal gradient across a thermoelectric device is the key to convert heat energy into electricity.^{1,2} It means that thermoelectric conversion cannot occur under a uniform temperature environment where the thermoelectric element does not experience a thermal gradient owing to thermal equilibrium.

Here, we propose a thermoelectric device that can produce a thermal gradient and generate electricity even in a uniform-temperature environment. We introduced a metamaterial absorber (MA), which comprised a silver mirror layer and silver microdisk arrays sandwiching a transparent calcium fluoride layer, at the one end of a thermoelectric device made of bismuth antimony telluride. The MA absorbs thermal radiation emitted from the surrounding medium, resulting in local heat generation as a consequence of absorption loss.^{3, 4} The local heating propagates to the thermoelectric device, leading to an additional thermal gradient. The heating efficiencies of the MA electrode and the opposite electrode of the device are unbalanced, which induces the Seebeck effect and results in electricity generation.

We attached the MA-fabricated copper electrode on one end of a thermoelectric device (Fig. 1(a-c)). On the other end, we loaded a control electrode as an inactive absorber. We placed this device in a uniform temperature environment at 364 K. Using the large difference in absorptivity of the device edges produced by the MA, a temperature gradient is produced even when the device is subjected to uniform and isotropic thermal radiations. Unlike conventional thermoelectric devices, the metamaterial thermoelectric device can collect and extract thermal energies from the surrounding medium.

Figure 1(d) presents dependence of the output voltages generated on the MA device and a control device on the measured environmental temperature. A control device has control electrodes at both ends. The output voltages generated across the MA thermoelectric device showed significant temperature dependence, whereas those generated on the control device did not show temperature dependence.

This result indicates the mechanism of metamaterial thermoelectric voltage generation in a uniform-temperature environment. MA absorbs thermal radiation emitted from the surrounding environment and generates local heating due to absorption losses by the MA. The local heat propagates to the thermoelectric device via a copper electrode, resulting in an additional thermal gradient across the thermoelectric device and subsequent output voltage generation.

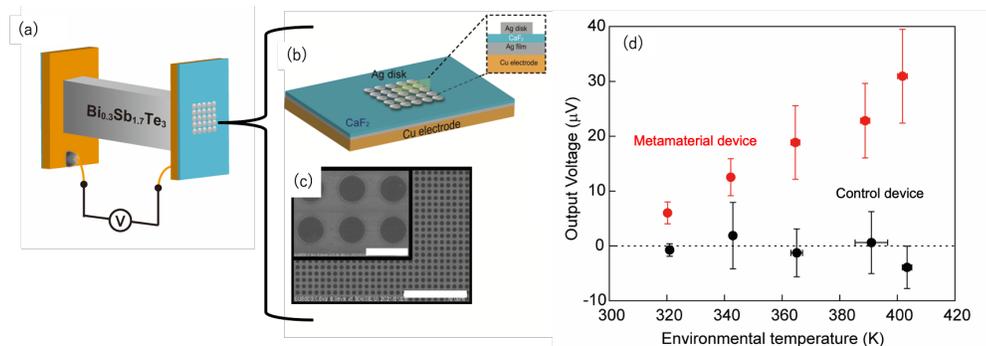


Fig. 1 Schematics of (a) a thermoelectric device loaded with the metamaterial electrode and (b) metamaterial array. (c) Dependence of the output voltages generated on the metamaterial device (red) and a control device (black) on the measured environment temperatures.

References

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