Near-field Measurements of Terahertz Meta-atoms with Localized Terahertz Sources

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1. Introduction

Terahertz (THz) metamaterials is very attractive due to their fascinating electromagnetic properties and potentials for building unique optical components and devices[1]. The meta-atom, an elementary unit of the metamaterial, is an electromagnetic resonator with non-zero magnetic and electric dipoles. Coupling between the meta-atoms and THz waves has great attention to investigate the dynamics of the metamaterials. However, the majority of THz metamaterial studies so far has focused on investigating the response of the meta-atom when a few hundred or thousands of its neighbor meta-atoms are excited with far-field THz waves. Then one or several of the meta-atoms are measured with far-field THz-wave and near-field probe. Therefore, those studies using the near-field probe are overlooking the details of the interaction between local THz electromagnetic field and a meta-atom. On the other hand, we have developed a scanning laser THz near-field imaging system[2]. In the system, a nonlinear optical crystal was employed as a THz emitter and THz waves were locally generated in the process of optical rectification at the irradiation spots of femtosecond laser beams. By setting samples in the vicinity of the THz source, THz-TDS and THz imaging of samples of sub-THz wavelength scale have been achieved. Since the size of the generated THz radiation source is smaller than that of meta-atom, the technique allows us to investigate the near-field coupling effects between a single excited meta-atom and its neighboring non-excited meta-atoms[3]. Therefore, in this study, we present direct measurements of the interaction of THz radiation with the meta-atoms of a THz metamaterial by using this system.

2. Experimental results

Figure 1(a) shows an optical microscope image of the fabricated metamaterial sample. A split ring resonator (SRR) which has a diameter of 84 μm with a gap of 5 μm and the linewidth of 10 μm was periodically patterned by using conventional photolithographic technique and radio-frequency sputtering of a 1-nm-thick adhesion layer of titanium on a 500-μm-thick (110) oriented GaAs wafer, followed by deposition of 430 nm of gold film. Figure 1(b) shows the THz transmittance spectra through a meta-atom when the period was fixed at 120 μm and the number of the meta-atoms was varied at 1x1 unit, 3x3 units and 5x5 units. It is found that we could observe LC resonances at 0.16 THz for the case of 1 unit and almost around the 0.2 THz for the cases of 3x3 and 5x5 units arrays. For the case of 1x1 unit, the observed resonance exhibits a low Q factor and the resonant frequency is shifted towards lower frequency compared with the other cases. This frequency can be considered as an unperturbed resonance of a simple LC circuit. Once we have 3x3 units arrays, the inductive or capacitive coupling among the SRRs can turn on, causing a shift of the resonance frequency and eventually modification of the resonance line width. It is also observed that the transmittance at the resonance is decreasing with an increase of number of the meta-atoms. This is because the excited meta-atom became a power feeding point and affected neighboring and the surrounding meta-atoms can be worked as amplifiers to enhance the LC resonance response.

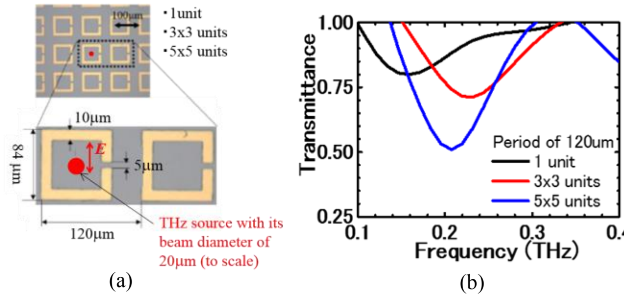

Fig. 1 (a) an optical microscope image of a few arrays of single split ring meta-atoms and (b) measured THz transmittance spectra through the meta-atom when the periods are fixed at 120 μm and the number of meta-atoms is varied at 1unit, 3x3 units and 5x5 units.

3. Conclusions

We demonstrated the direct measurement of meta-atom by exciting with a locally generated THz waves and succeeded in observing the effect of coupling of the electric field to neighbor meta-atoms. The obtained data help us to understand details of coupling between the meta-atoms and THz waves, which is needed for future active THz metamaterial designs and development of compact and high-sensitive biosensors. Furthermore, this technique can also visualize the excitation of unique individual modes of meta-atoms through the THz images obtained by scanning the laser for THz radiation. We will also show these modes of meta-atom both in time- and frequency-domain.

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References

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