Research on the Radiative Eigenmodes in Terahertz Wave Region from Metallic Slit Array

Osaka Univ.[1], Inst. for Laser Tech.[2], Univ. of Fukui[3],

Thanh Nhat Khoa Phan[1], Dazhi Li[2], Kosaku Kato[1], Masahiko Tani[3],

Masashi Yoshimura[1], and Makoto Nakajima[1]

E-mail: phan@ile.osaka-u.ac.jp

1. Introduction

Many researches for the Free Electron Laser (FEL) based on the Smith-Purcell effect have been conducted. The electromagnetic radiation emits from diffraction grating when an electron beam flied over. In the simplest grating structure, radiation extracted from this effect is not in the direction of the electron beam movement, but at an angle satisfying the relation:

$$\frac{c}{f} = \frac{L}{|n|}\left(\frac{1}{\beta} - \cos\theta\right)$$

where c is speed of light, f is the frequency of emitted radiation, L is the grating period, n is the order of the diffraction, and $\beta = v/c$ is the ratio of electron beam velocity v and c.

The dielectric-loaded metal grating has been proposed [1] to enhance the extraction of radiation. Surface plasmon polariton (SPP) on graphene has also been studied [2], but a combination with vertical side wall must be made to upshift the dispersion line of SPP, thus enable the release of terahertz (THz) wave into free space at inclined angle.

In this research, we study the radiative eigenmodes in two dimensional metallic slit arrays by using THz time-domain spectroscopy (THz TDS). Understanding these modes will help us in further study on the resonant interaction between them and the electron beam, and subsequently to improve the extraction of terahertz radiation.

2. Experiment

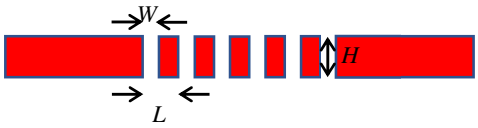

Figure 1: Dimensions of the fabricated slit array

The schematic structure of slit array is shown in Fig. 1. The sample was fabricated by laser machining using femtosecond laser pulses. The parameters of the slits array shown in Fig. 1 were L = 100 µm, W = 50 µm and H = 100 µm. THz TDS was performed by TAS7500-TS (Advantest) to measure the transmittance at various incidence angles θ. Numerical calculation was performed using finite element method in COMSOL software.

3. Results

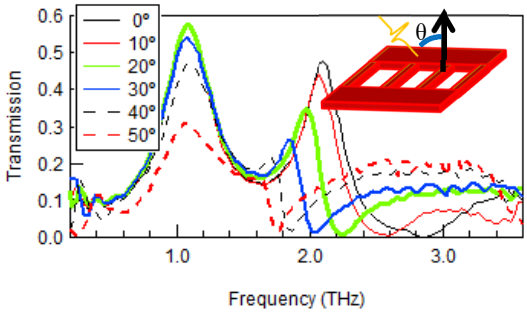

Figure 2: Transmission spectra of the metallic slit array

Figure 2 shows the experimental results of THz transmission spectra when incidence angles were varied. The first high transmission peaks at frequency around 1.1 THz are attributed to waveguide modes, and the frequencies remain virtually unchanged. The second peaks are attributed to waveguide modes of second order, whose eigenfrequencies show strong redshift at high incidence angles. We confirmed the radiative eigenmodes directly and the frequencies of these modes are in good agreement with the result of the numerical calculations.

4. Conclusion

We demonstrated the experimental study on the THz radiative modes for the metallic slit array. The measured frequencies of the first modes show no shift and second modes show large redshift, and were found to be in agreement with the result of the calculation.

This work is partially supported by the Cooperative Research Program of Research Center for Development of Far-Infrared Region, University of Fukui (H29FIRDM016B), the joint research project of the Institute of Laser Engineering, Osaka University (2017B1-LI), and KAKENHI (16K04987).

Reference

[1] W. Liu et al, Physics of Plasmas 23,033104 (2016).

[2] D. Li et al, Appl. Phys. Lett. 110, 151108 (2017).