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Ultrafast imagine of the phononic response of split-ring-resonator structures

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[2]　　　Purpose of research

The objective is to investigate the vibrational response of nanoscale split-ring resonators (SRR) in square-lattice arrays to ultrashort-pulse pumping and probing, not yet achieved for acoustic vibrations[1]. In particular we aim in elucidate the interaction between the high frequency ultrasonic strain and the metamaterial's magnetic resonances, and to find how to optimize it. We also aim to probe the effect of the split-ring height (~20 nm) and size on its acousto-optic response. Magneto-optical acoustic modulators are a possible spin off.

The gold SRR samples are made by electron lithography. Each split ring resonator is approximately 200 microns square, with a lattice constant of 340 nm, and gold thickness 20 nm.

We propose by collaboration with Shizuoka University to better characterize the sample optical modes by white-light spectroscopy, and thereby use the results to carry out tuned optical pump and probe experiments on ultrashort time scales. This should reveal the role of the plasmonic modes on the optical modulation produced by the phononic modes of the samples.

Research content

Samples:

We aimed first to characterize the sample, as shown in Fig. 1 by white light spectroscopy, for which a purpose-built setup was constructed, as shown in Fig. 2. The results of the white light experiments were not as expected, so we concentrated on numerical simulations of the optical reflectance spectrum from the sample to investigate this.

Measurements

After doing SEM imaging of the sample, we carried out characterization with white-light spectroscopy using a white-light laser spectrometer from the near-IR to visible wavelengths. The spectra were taken at normal incidence with two perpendicular optical polarizations. In addition, simulations of the normal-incidence optical reflectance spectrum were made using Comsol.

[3]　　　Results

Figure 3 shows the white-light spectroscopy results, showing a clear dependence of the spectra on the orientation of the incident optical polarization. Unexpectedly, several peaks appeared in the spectrum. To elucidate this behavior we carried out simulations with Comsol electromagnetic-wave simulation software.

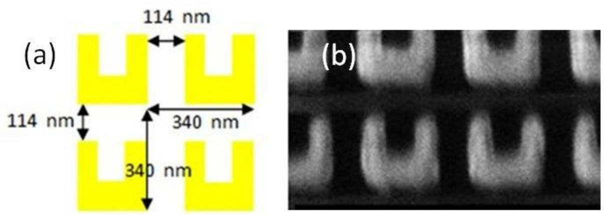

Fig. 1: (a) Schematic diagram of the gold SRR (on a silica substrate). (b) A scanning electron micrograph of the sample. The faint horizontal lines are thought to be artifacts.

The results of the software simulations are shown in Fig. 4. Clearly multiple peaks are not predicted. One possible reason for the discrepancy could be the presence of the horizontal lines seen in the SEM images, that might represent a sample that is not just an array of SRR. However, for two reasons we think this is not the case. 1) The Swinburne University group that made the sample suggest these lines are just artifacts of the SEM imaging process. 2) We also simulated the spectra with the presence of extra lines, but the results did not agree with the experiment (no extra peaks appears in the frequency range of interest).

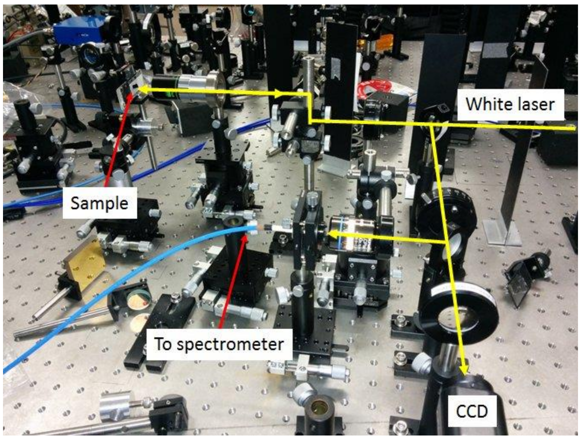

Fig. 2: Diagram of the optical setup to measure the white light spectrum, making use of a white light laser.

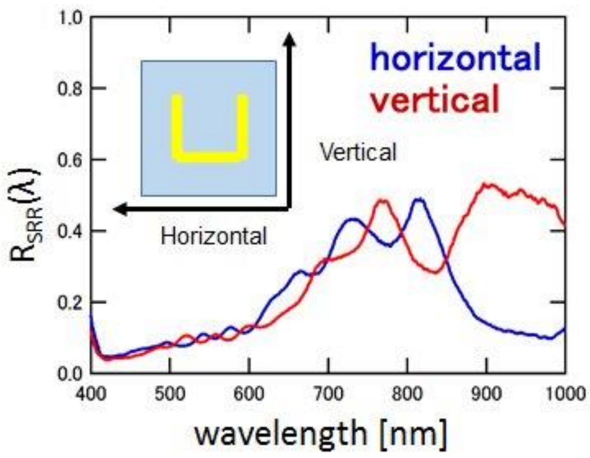

Fig. 3: Results of white light spectrum measurement

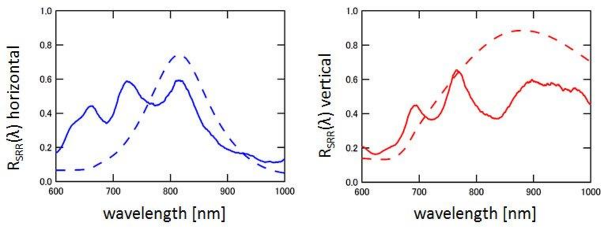

Fig. 4 Results of numerical simulations compared to experiments for horizontal and vertical polarizations. The simulation is shown with the dashed line. The experimental run for these results was from a different area on the sample compared that shown in Fig. 3

At the moment we are trying to understand the reasons for the discrepancies between the simulations and experiments before proceeding to pump and probe experiments.

Future prospects and research

We need to achieve agreement between optical reflectivity spectrum simulations and experiment before being able to conduct meaningful ultrafast pump and probe experiments. We shall continue to investigate the discrepancy with the aid of additional samples. Then we hope to reveal the role of the plasmonic modes on the optical modulation produced by the phononic modes of the samples. In terms of applications, this will open the way to ultrafast SRR acousto-optic devices.

[4] Documentation

[1] Linden et al., IEEE J. Sel. Topics in Quantum Electr. 12, 1097 2006

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