Ultrafast imaging of phonons in plasmonic egg boxes

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The ability to localize light on the nanoscale using SPP promises a revolutionary means for highly integrated and fast information processing. In order to modulate light in such structures, various possibilities exist, one of which is the use of acoustic waves. However, so far no studies involving the imaging of SPP-acoustic interactions have been carried out. Here we report on the optical imaging with micron spatial resolution of the gigahertz vibrational field excited in a plasmonic structure made up of a periodic array of gold dishes. Numerical simulations of these gigahertz acoustic phononic modes of the structure confirm the main acoustic resonances optically observed.

The sample consists of an array of microscopic gold spherical dishes on a silica substrate, much like the form of an egg box, as shown schematically in Fig. 1(b).[1] Dishes of diameter ~1 μm were prepared by an electroplating technique. By varying the amount of metal deposited, the geometry of the structure is altered to form triangular-lattice arrays of gold dishes of varying depth. This sample therefore provides a useful test bed for SPP-phonon interactions at gigahertz acoustic frequencies.

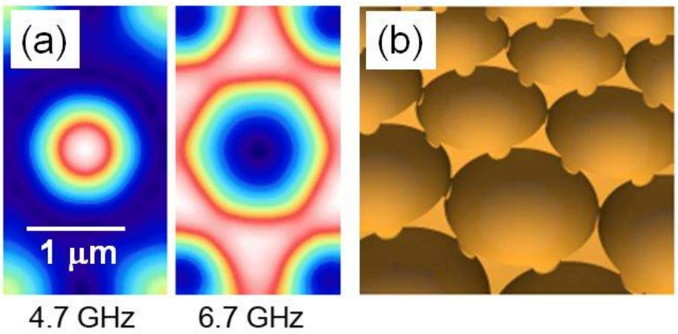

Fig. 1: (a) Intensity change maps for the ultrafast vibration of a section of a nanovoid array of Au dishes of diameter 1600 nm. Excitation at λ=800 nm and probing at 400 nm with 200 fs pulses. (b) Schematic diagram of several unit cells of the sample.

By focusing ultrashort laser pulses of duration 200 fs , wavelength 800 nm, and repetition rate 80 MHz onto the sample surface we generate a thermoelastic expansion, thereby exciting standing and travelling acoustic waves in the gigahertz region. These vibrations are detected by synchronous probe laser pulses of wavelength 400 nm focused to a ~1 μm spot, allowing the observation of gigahertz resonances of the dishes. Scanning the sample position allows in addition the twodimensional imaging of the vibrational field. By temporal Fourier transforms we map the vibrational amplitude at each frequency to characterize the acoustic modes. We find that the dishes form phonon resonator cavities, which act to trap and store sound waves. An example of the spatial distribution of the optical-probe relative intensity change at two different vibrational resonances are shown in Fig. 1 for a sample with 1.6 μm diameter dishes in which the height is 3/5 of the diameter. In Fig. 1 (a) the left hand image shows the response at 4.7 GHz, dominated by a mode with a maximum vibrational response at the centre of the dish. The right hand image in Fig. 1 (a) shows the response at 6.7 GHz, dominated by vibrations between the dishes. We have in addition modelled the dish response with a finite-element time-domain technique. This has been done for a series of dish heights and diameters, and the dominant acoustic resonance frequency variations were found to agree well with experiment.

These studies have so far been carried out with fixed optical wavelengths for the pump and probe beams. In future these will be independently scanned to determine the role of the SPP modes on the vibrational mode spectrum and their detection. This research, drawing on the ability to simultaneously confine acoustic and plasmonic optical fields on the nanoscale, may have applications in sensing and in active plasmonic devices.

References

[1] R. M. Cole et al., Nano Lett. 7, 2094 (2007)
[2] F. M. Huang et al., Nano Lett. 11, 1221 (2011)