Phonon-polariton based nano-split ring resonator

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***Abstract*—Phonon-polaritons are being studied under a broad range of aspects including slow light, hyperbolic materials response, and localized resonances. Here, we show the use of phonon-resonance based conductance to engineering split ring resonators (SRRs) with high qualtiy factors, designed to operate in the reststrahlen band around 1400 cm^{-1}. SRRs have proven to be a useful tool in the fields of metamaterials, light matter interaction, and non-linear optics. An important limitation in these applications are the ohmic losses in gold and other metals. In contrast, transvers optical phonons have large oscillator strength and low scattering rates. We present near-field point spectra and monochromatic near-field images of phononic SRRs which reveal narrow-band localized resonances. We find that these localized modes can be described as hybridized surface modes, and propose the use of a lumped element model to describe the LC-resonance for the strongly dispersive AC-conductance found in polar materials.**

For our experiment, 20 nm thin flakes of enriched hexagonal ^{10}BN [1] were exfoliated onto a CaF_2 substrate. The SRR structures were patterned with reactive ion etching using a gold mask defined by electron beam lithography. Point spectra recorded using a NanoFTIR setup show a series of characteristic narrow resonance peaks. Subsequent phase resolved imaging using a scattering scanning near-field optical microscope (s-SNOM) with monochromatic illumination with a MirCAT quantum cascade laser reveal well mode patterns for up to 10 modes (the near-field scattering amplitude of the third excited mode is shown in the inset in figure 1).

The dispersion of these modes can be well described by the hybridization of the surface modes [2], [3] which propagate on the inner and outer bend surfaces of the LC-structure. Simulated dispersion relations for uncoupled modes are shown as function of angular momentum in figure 1. For a given angular momentum (i.e. same number of nodes along a ring), their frequencies do not match due to the actual different linear length of the inner and outer ring surface (i.e. $l \propto r$). Since the ring structure is narrower (≈ 50 nm) than the decay length of the surface phonon-polariton, the surface modes hybridize, forming a symmetric and antisymmetric mode. Only the former is confined to the h-BN structure and leads to the observed discrete resonances of the SRR. Treating the reactive response of the phonon-resonance in the framework of kinetic inductance, we propose a lumped element circuit model which allows to capture both, geometrical and dispersive aspects of the strongly subwavelength resonant structures.

The description of phononic nano-structures using the lumped elements circuit model may trigger a more engineering kind of approach to phonon-polariton-devices. Thanks to their low intrinsic scattering losses compared to gold, phononic materials can enable new applications at the modest cost of a narrow frequency band of operation for any polar material.

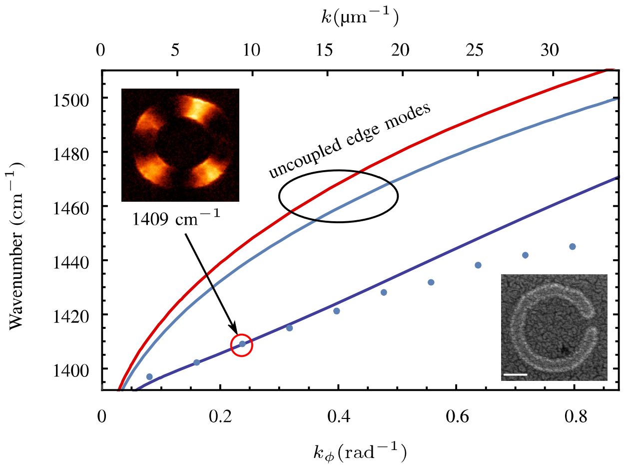

Fig. 1. Dots are measured resonance frequencies for SRR with radius of 160 nm plotted versus angular momentum. Uncoupled edge modes are calculated for a straight waveguide using the 2D-mode solver in Comsol. The purple line which follows the measured resonance frequencies results when considering hybridization of the uncoupled edge modes. The upper left inset shows the scattering signal of the SRR measured at 1409 cm^{-1}. Lower left inset is an SEM image of the SRR structure (scale bar is 100 nm). The upper momentum axis was calculated for an effective ring radius of 160 nm.

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References

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