Novel nanophononic structures and devices

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Through the engineering of semiconductor nanostructures it is possible to control both the dynamics and the interactions between photons and phonons at ultrahigh frequencies and reduced scales. In this presentation, I will describe devices based on semiconductor multilayers optimized to generate, detect, and confine acoustic phonons and possible applications and devices.

Acoustic-phonons in the GHz-THz range (i.e. acoustic waves with wavelengths in the 1-100 nm range) appear as a suitable platform to study complex wave phenomena, motivating the development of nanophononic devices. The strong interactions with other excitations in solids extend the range of applications to other fields such as nanoelectronics, photonics, communications, NDT, optomechanics, and quantum optics. Contrary to what happens in standard opto-acoustics, at these scales, the wavelength of the photons is comparable or much larger than the wavelength of the acoustic waves.

Coherent phonon generation by optical pump-probe experiments has enabled the study of acoustic properties at the nanoscale in planar heterostructures, plasmonic resonators, cells, micropillars, and nanowires. These experiments rely on the optical mode matching between the incident pump and probe laser fields and the optical modes of the structure under study. The efficient generation of coherent acoustic phonons relies on an efficient coupling of the pump field into the system, while the sensitive detection of phonons requires an efficient coupling of the probe to the optical mode undergoing a phonon-induced modulation. Since the implementation of these experiments usually requires a long mechanical delay line, the main practical challenges for its actual implementation are thus (1) stability of the optical mode overlap, (2) reproducibility of the excitation conditions, and (3) high power densities limiting the range of compatible samples. These shortcomings have so far been a roadblock in establishing the pump-probe as a quantitative spectroscopy tool for nanoacoustics.

In this work, we simultaneously solve the three aforementioned challenges by integrating fibered systems into pump-probe experiments [1], lifting the necessity for any optical alignment during the experiments. We aligned and glued a single mode fiber onto an optophononic micropillar beforehand as shown in Fig. 1. Our approach allows us to observe stable coherent phonon signals over at least a full day even at extremely low excitation powers of 1μW. This excellent stability enabled us to perform detailed power dependence studies revealing complex dynamics of the optical and phononic modes. Taking these dynamics into account, we are able to optimize excitation conditions and observe a mutual coherence between the optical and acoustic mode. The monolithic sample structure is transportable and provides a means to perform reproducible plug-and-play experiments. The integration with fibers might also establish the missing link between high frequency acoustic phonon engineering and stimulated Brillouin scattering in structured optical fibers.

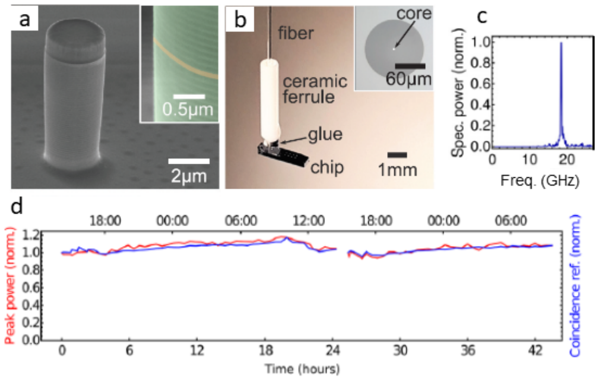

Fig. 1. **(a)** Optophononic micropillar cavity. **(b)** Device integrated into a single mode fiber. **(c)** Nanophononic response of the device measured by pump-probe spectroscopy. (d) Stability of the response over 42h. Figure adapted from Ref. [1].

In the second part of this presentation, I will describe a series of nanophononic devices based on planar and micropillar resonators, including Fabry-Perot [2], topological [3,4], and adiabatic designs [5]. I will describe how we engineered an optophononic 3D elliptical micropillar resonator based on AlAs/GaAs superlattices to simultaneously confine light and sound with an acoustic mode at 18 GHz. This design results in enhanced optomechanical interactions [2,6]. Due to the pillar ellipticity, the degeneracy of horizontally (H) and vertically (V) polarized cavity mode is lifted, leading to polarization-dependent reflection coefficient r_H and r_V. The splitting between the two optical modes depends on the ellipticity and size of the pillar and enables novel optical filtering strategies.

By bridging the gaps with other research fields such as optomechanics, plasmonics, polaritonics, and quantum technologies, nanophononics has great potential to unlock new paths in the engineering of nanodevices and unveil a plethora of novel and exciting physical phenomena.

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