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Observation of acoustic avoided crossing in sub-wavelength diameter fiber

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Abstract: We experimentally demonstrate the first phonon anticrossing in an optical fiber taper microwire by means of the Brillouin scattering nonlinearity. Numerical calculations based on electrostriction modelling explain the result.

The rich and complex dynamics of light and sound interactions in tiny optical waveguides has recently gained much interest because of their experimental realization in emerging key areas of photonics [1-4]. For instance, we recently demonstrated the generation of a new class of surface acoustic waves in a subwavelength-diameter silica optical fiber taper [5]. In such thin silica wires, boundary conditions induce a strong coupling of shear and longitudinal displacements, resulting in a much richer dynamics of light interaction with hybrid acoustic phonons. Avoided crossings can thus occur due the strong photon-phonon coupling and to the fact that these acoustic modes are no longer orthogonal and thus can interact. This interaction can be sufficiently strong enough for certain acoustic frequencies to be forbidden at some anti-crossing points, giving rise to new characteristics such as Brillouin frequency gap.

In this work, we report the first observation of avoided crossing for acoustic waves in a subwavelength optical fiber. This was achieved in a highly nonlinear polymer-coated chalcogenide (As_2Se_3) optical microwire through a detailed investigation of the *s*pontaneous Brillouin backscattering measurements based on a heterodyne detection [7]. We show in particular that the Brillouin frequency shift no longer depends linearly on the pump wavelength, however it exhibits a large frequency gap due to avoided crossing. By tuning the laser wavelength, it is actually possible to vary the acoustic wave vector through the phase-matching condition and to observe the effect of anti-crossing.

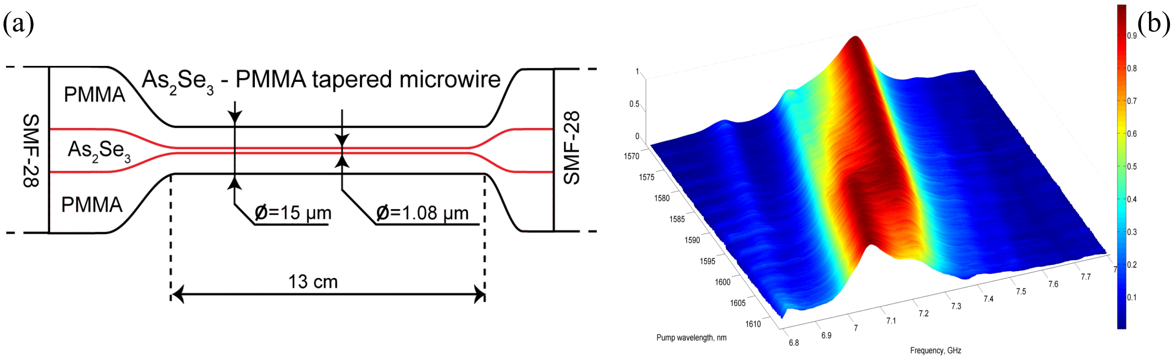

Figure 1 (a) Scheme of the hybrid As_2Se_3-PMMA optical microwire used to observe avoided crossing effects. (b) Experimental Brillouin backscattering spectrum as a function of pump wavelength showing the nonlinear frequency gap due to avoided crossing at a pump wavelength of 1600 nm.

The PMMA-As_2Se_3 microwire is schematically shown in Fig. 1(a). It has a core diameter of 1.08 µm and a length of 13 cm. The microwire is butt-coupled to single-mode fibers and permanently bonded with UV-epoxy [7]. As a pump laser, we used a narrow-linewidth DFB laser tunable from 1526 nm to

1613 nm with an output power of 10 mW. Figure 1(b) shows the output experimental Brillouin spectrum as a function of the laser wavelength. At a wavelength of 1600 nm, we clearly observe the Brillouin frequency gap due to acoustic avoided crossing. The Brillouin spectrum simultaneously exhibits two detuned acoustic resonances for this specific wavelength.

Numerical calculations of the Brillouin spectrum using the elastodynamics equation subject to an *electrostrictive* force presented in the figure 2 are in good agreement with experimental results We computed the kinetic elastic energy as a function of frequency for different diameter of microwire, equivalent to a variation of acosutic wave vector [9,10]. We can see in Fig. 2 the avoided crossing between two hybrid acoustic waves due to small dimensions of mcirowire.

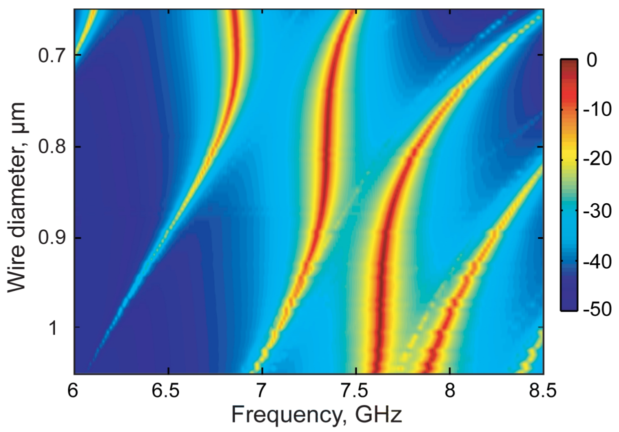

Figure 2 Numerical simulations: Color plot of elastic energy of acoustic resonance generated by electrostriction versus the acoustic frequency and for a wire core varying from 0.6 µm to 1µm from top to bottom.

To conclude, we have shown the existence of acoustic avoided crossing by mapping the phonons dispersion in a sub-wavelength diameter chalcogenide microwire. These findings can help for further understanding of light-sound interactions in subwavelength nanoscale waveguides.

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