Silicon socket layer for highly tunable phonon-phonon coupling in integrated circuits

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Abstract: We investigate acoustic coupling between two silicon waveguides through a 60nm-thin silicon “socket” layer. The coupling turns out to be highly dependent on the socket length. The structure holds promise for microwave processing.

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Stimulated Brillouin scattering was recently demonstrated on the silicon-on-insulator platform using partially suspended [1] and free-standing [2] silicon nanowires. These structures harnessed a good overlap between the quasi-TE polarized fundamental optical mode and a 10GHz acoustic mode. The acoustic mode was essentially the fundamental Fabry-Pérot-like vibrational mode of the nanowire [1]. Here, we focus on quasi-TM polarized light (fig.a). Thus, we rotate both the optical and acoustic field by 90° (fig.b) with respect to the TE-based work [1, 2]. This allows for better power handling (lower two-photon absorption), and higher mechanical frequency (17.6GHz instead of 9GHz). Crucially, this rotated acoustic mode has a small displacement at the connection to the socket (fig.d). Therefore, it generates relatively weak coupling to the adjacent waveguide. This is important to realize a 2nd order radio-frequency filter response [3]. This small displacement also allows us to avoid the design of a phononic bandgap, in contrast to a previous silicon nitride structure [3]. Besides microwave filtering [3], using the socket layer as a phonon coupler may find use in integrated phonon networks [4, 5].

Our design is composed of two 600nm × 220nm silicon waveguides (WG-1 and WG-2) connected by the 60nm-thin socket layer (Fig. c). This socket layer can be fabricated in standard silicon photonics fabs (www.europractice-ic.com/). We simulated both the photon-phonon (of a single waveguide) and the phonon-phonon coupling (between the waveguides) with the finite-element solver COMSOL. The acoustic coupling generates a symmetric and anti-symmetric acoustic mode, whose difference in frequency is $\mu$. The socket length offers a large tunability in coupling rate $\mu$: from 0MHz to 36MHz given only a 100nm change in socket length (fig.e). This shows, for the first time, how a thin silicon layer can be used to phononically couple silicon waveguides – and in a highly versatile manner. Besides its potential in microwave photonics [3], this layer could be used more generally, e.g. to couple out phonons from an on-chip mechanical laser into a phononic bus waveguide [6]. The physics of the coupler will be analyzed in detail elsewhere. Notably, this phonon-phonon coupler is not evanescent. In particular, this coupling does not decrease monotonically (fig.e).

The tunability allows us to match the coupling rate $\mu$ to the mechanical loss rate $\kappa$ of our oscillator for a large range of mechanical quality factors: from 500 to more than a million. This matching condition allows us to maximize phonon-mediated information transfer between the two waveguides. The cross-phase modulation efficiency is directly related to the Brillouin gain coefficient in a single waveguide [3]. The Brillouin interaction is dominated by the boundary nonlinearity, unlike before [1, 2]. Assuming a mechanical Q of 1000, we simulate reasonable efficiencies of about 1000$m^{-1}W^{-1}$. Therefore, there is little doubt that this phonon-phonon coupling method can indeed be measured via Brillouin scattering.
In conclusion, our analysis demonstrates that nanoscale silicon waveguides can be coupled acoustically in a highly tunable manner via a thin silicon socket layer. We expect experimental results in the coming months.

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References


