Scalable Nanomechanical Computing

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Nanomechanical computers promise radiation robust, low energy information processing. However, to date mechanical logic gates have generally required inefficient electrical interconnects [1]. No scalable purely mechanical approach has so far been devised. Here we demonstrate a scalable, CMOS-compatible nanomechanical logic gate (Fig 1a) [2]. The gate operates by using the bistability of a nonlinear Duffing resonator (Fig 1b). It is efficiently coupled to input and output nanomechanical waveguides, which provide an all-acoustic equivalent of electrical wires [3]. Crucially the gate preserves the spatio-temporal characteristics of the signal, allowing the output of one gate to serve as the input to another. We experimentally achieved a boolean-complete set of logic gates using only mechanical inputs (Fig 1c, Fig 1d). Realistic miniaturisation of our design could allow gigahertz frequencies and an energy cost approaching the fundamental Landauer bound, sidestepping 'Boltzmann's tyranny'—the thermodynamic limit on the efficiency of electrical gates. This result presents a pathway towards large-scale nanomechanical computers, as well as neuromorphic networks of oscillators that solve computationally hard problems [4].

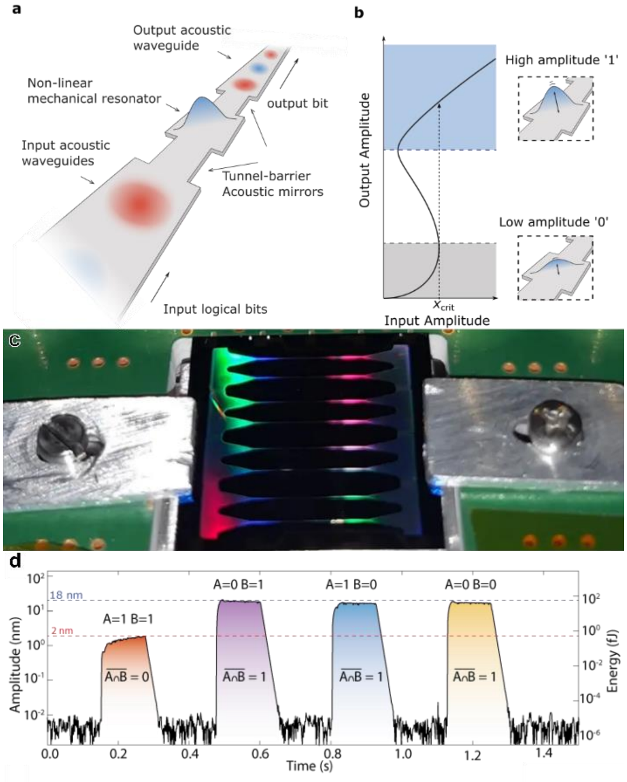

Figure 1 - (a) The logic is performed by a nonlinear resonator, which connects to input and output waveguides through acoustic tunnel barriers. (b) '0' and '1' values are represented by the bistable vibration amplitude. (c) The device was fabricated using CMOS techniques from high tensile-stress silicon nitride. (d) Demonstration of a NAND gate: time series of gate amplitude as it is sequentially provided with different logical inputs.

[1] J. Wenzler et al., Nano Lett., 14, 89-93 (2014).

[2] Romero et al., N.P. Mauranyapin, R. Kalra, T.M.F. Hirsch, C.G. Baker, G.I. Harris, and W.P. Bowen. "Scalable Nanomechanical Logic". arXiv:2206.11661 (2022).

[3] Romero et al., Phys. Rev. Appl., 11, 064035 (2019). N.P. Mauranyapin et al., Phys. Rev. Appl., 15, 054036 (2021).

[4] C.D. Schuman et al., Nat. Comp. Sci., 2, 10-19 (2022)