Voltage-sustained self-oscillation of a nanomechanical electron shuttle

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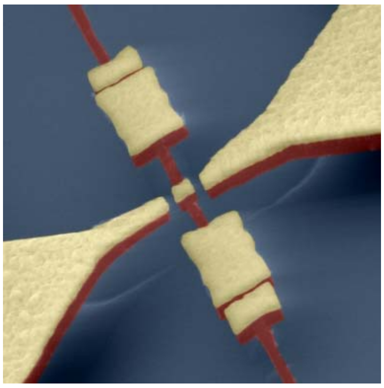
In the past years high stress silicon nitride has received considerable interest as a robust and high Q material for nanomechanical systems. Here we present a nanomechanical charge shuttle, which is a model system to investigate the coupling of electronic transport properties and mechanical degrees of freedom: A nanoscale metal island hosted by a resonator that is oscillating between two opposing electrodes can be used to mechanically transport charge and thus produce an electric current [1]. We have realized such an electron shuttle on a doubly clamped silicon nitride string subject to high intrinsic tensile stress. Typical devices consist of large arrays of shuttles with customized mechanical resonance frequencies in the range of 1 – 10 MHz that are shunted between the source and drain electrode. Frequency multiplexing is employed to individually address single shuttles.

Stable shuttling operation in the quasi-ohmic, high temperature regime could be demonstrated in an acoustically actuated shuttle at 20 K [2]. While acoustic operation implemented by a piezo transducer ensures complete decoupling of the measured electrical signal from the drive and thus allows for clean transport measurements with linear current – voltage curves, it complicates low-temperature operation due to the inevitable dissipation of the piezo. Despite ongoing island miniaturization to increase the shuttle's charging energy this has so far impeded the transition to the Coulomb blockade regime.


Nanomechanical charge shuttle

An alternative approach to efficient nanomechanical systems relies on self-oscillation, i.e. the generation of a periodic vibration by a constant driving force. Self-sustained oscillation in nanomechanical systems has been observed in optomechanical systems driven by bolometric forces or radiation pressure, or in electromechanical systems with both external or internal feedback. Voltage-sustained self-oscillation of a nanomechanical charge shuttle has been theoretically predicted [1]. Here we present a nanomechanical electron shuttle operated solely by a DC-Voltage that is applied between source and drain [3]. After triggering the resonator via conventional actuation, the oscillation is sustained by repetitive charge reversal at the electrodes. Due to the minimal energy input of this driving scheme, operation at millikelvin temperatures becomes feasible. This may pave the way into the Coulomb blockade regime of discrete mechanical single electron shuttling.

[1] L. Y. Gorelik et al., Phys. Rev. Lett. 80, 4526 (1998).
[2] D. R. Koenig, E. M. Weig, J. P. Kotthaus, Nature Nanotechnology 3, 482 (2008).
[3] D. R. Koenig, J. P. Kotthaus, E. M. Weig (in preparation).