"SUPPORTING INFORMATION"

Tuning mechanical modes and influence of charge screening in nanowire resonators

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Quality factor, Q ***and amplitude of vibration,*** z_{amp}^{reso}

To extract quality factor Q and amplitude of vibration z_{amp}^{reso}, we fit Lorentzian lineshape of measured data using Eqns.1 and 2 of main text (Fig.1). The Q of our devices are low. We think there the reason for low Q is that in our devices gold, a soft metal, is the clamping material, which may lead to some clamping losses. Some preliminary measurements have been made by coating the NWs with Al_2O_3 and the Q is observed to improve.

Coupling of modes

If we assume that there are asymmetries in the cross-section of the nanowire, then the capacitance C will depend not only on the coordinate in the direction perpendicular to the gate plane (z axis), but also on the transverse direction (y axis) parallel to the gate plane and perpendicular to the NW. The motion in the transverse y direction will be weakly affected by the gate voltage V_g^{DC}, as compared to motion perpendicular to the gate plane.

For small oscillations [1] (at frequency f) about equilibrium with two degrees of freedom (z and y), the matrix of coefficients appearing in the Hamiltonian takes the form

$$\begin{pmatrix} 4\pi^2 m f^2 - K_i^z + \frac{1}{2}\frac{\partial^2 C}{\partial z^2}(V_g^{DC})^2 & \frac{1}{2}\frac{\partial^2 C}{\partial z \partial y}(V_g^{DC})^2 \\ \frac{1}{2}\frac{\partial^2 C}{\partial y \partial z}(V_g^{DC})^2 & 4\pi^2 m f^2 - K_i^y + \frac{1}{2}\frac{\partial^2 C}{\partial y^2}(V_g^{DC})^2 \end{pmatrix}$$

K_i^z, K_i^y are the intrinsic force constants for motion along z and y directions respectively. K_i^z and K_i^y are assumed to depend upon V_g^{DC} in a way similar to what we have discussed earlier.

$$\begin{aligned} K_i^z &= k^z + \alpha^z (V_g^{DC})^2 + \beta^z (V_g^{DC})^4 \\ K_i^y &= k^y + \alpha^y (V_g^{DC})^2 + \beta^y (V_g^{DC})^4 \end{aligned}$$

The non-zero off-diagonal element $\frac{1}{2}\frac{\partial^2 C}{\partial z \partial y}(V_g^{DC})^2$ in the matrix of coefficients mentioned above gives rise to coupling of the two modes and their mixing.

In our experimental data, for a certain value of gate voltage V_g^{DC}, one mode appears prominently while the other is comparatively faint. Only close to the region of level repulsion they are equally prominent. The mode for which the amplitude of oscillation is larger in z direction than in y shows up more clearly in our detection scheme. This is explained by our model (Fig.2). The ratio of amplitudes in z and y directions is higher for the blue mode at lower gate voltages before mixing, and for the red mode after mixing.

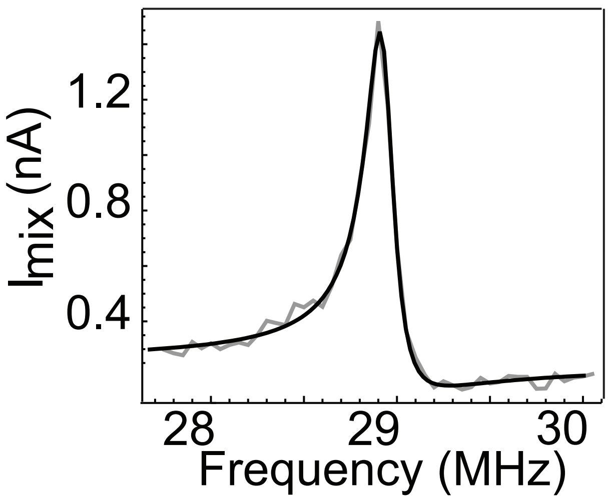

FIG. 1: Shows fitting of measured data.

However, we do not see mode mixing in all the devices (e.g. device-2), because this coupling due to asymmetry is dependent on the structure of the NW and may be negligible in many cases.

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[1] H. Goldstein, C. Poole, and J. Safko, *Classical Mechanics* (Pearson Education (Singapore), 2004).

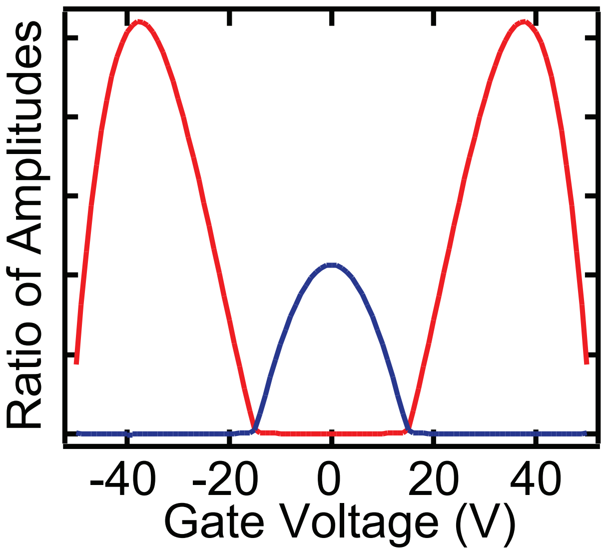

FIG. 2: Shows the calculated ratio of z and y - amplitudes of two modes (red and blue) for natural oscillations.

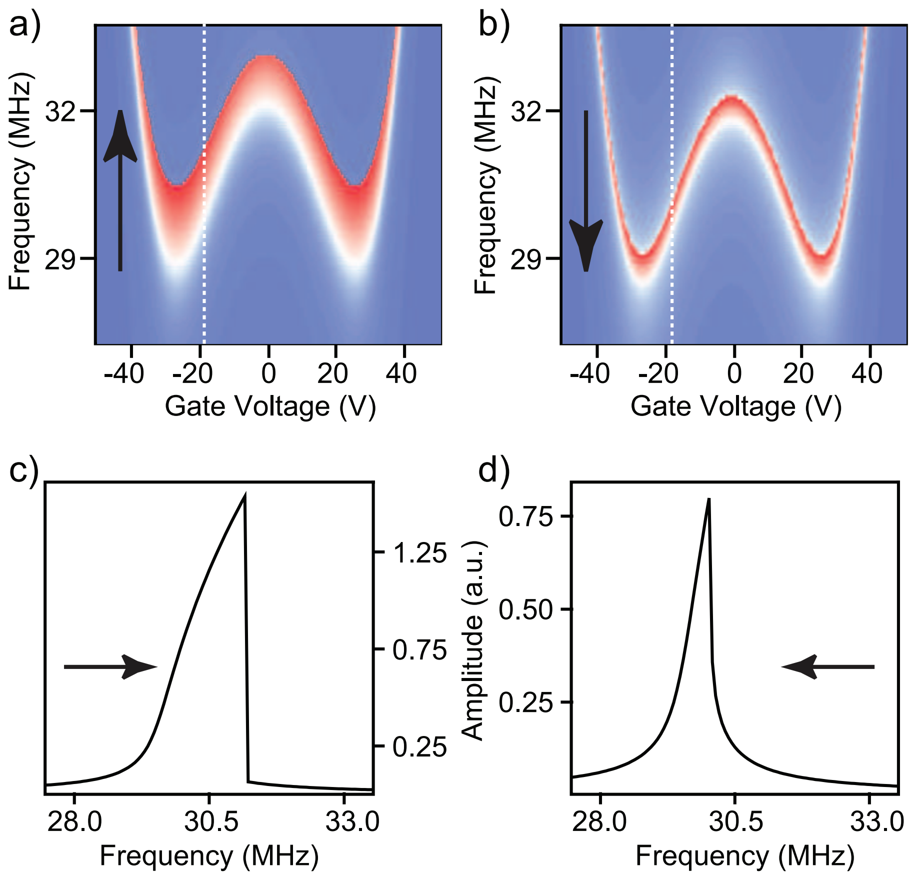

FIG. 3: a) and b) Colorscale plots of *calculated* amplitude of a resonator in the non-linear regime using duffing equation for increasing and decreasing frequency sweeps respectively. c) and d) Show the line plots of dashed line in 3a and 3b respectively. Arrows are showing frequency sweep direction.