Contactless, high throughput determination of electrical conductivity of one-dimensional nanomaterials by solution-based electro-orientation spectroscopy†

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Supporting Information

Electro-orientation torque vs Brownian motion: The electro-orientation torque $|\vec{T}_e|$ experienced by a spheroid suspended in a liquid of permittivity $\varepsilon_f$ due to a uniform AC electric field $\vec{E}$ acting on an induced dipole moment $\vec{p}$ is:

$$|\vec{T}_e| = |\vec{p} \times \vec{E}| = \frac{\pi}{3} ab^2 \varepsilon_f \text{Re}[K] E_0^2 \sin 2\theta,$$

(S1)

where $a$ and $b$ are the semi-major and semi-minor axes of the prolate spheroid. Re($K$) is the real part of the complex Clausius-Mossotti factor $K$ which is a strong function of electrical properties of the particle and the fluid, the frequency of the applied electric field and the aspect ratio of the particle:

$$K = \frac{\varepsilon_p - \varepsilon_f}{3(\varepsilon_f + (\varepsilon_p - \varepsilon_f)L_\parallel)},$$

(S2)

where the complex permittivities are $\varepsilon_p = \varepsilon_p - \sigma_p / \omega j$ and $\varepsilon_f = \varepsilon_f - \sigma_f / \omega j$, and $L_i$ is the depolarization factor given by $L_\parallel \approx \frac{1}{\varepsilon_p}[\ln 2\beta - 1]$. The aspect ratio of the prolate spheroid is defined as $\beta \equiv a/b$.

The electro-orientation torque can be compared to the thermal energy, $k_B T$, associated with the Brownian motion. For a typical electric-field strength of 100 V/mm, we find the ratio of orientational to thermal energies is on the order of $10^4$, suggesting that the Brownian motion is negligible. To further minimize

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the effect of Brownian motion, we find the alignment rates by fitting the measured angular position of the nanowires over relatively long times on the order of 3 seconds. For these reasons, we believe that the uncertainty in alignment rate due to Brownian motion is minimal in these measurements.

Supporting Figures

Figure S1: Direct-contact STM measurement of the $I$-$V$ curves with different probe spacings a) 2P-STM measurement of Si nanowire, b) 4P-STM measurement of Ge nanowire. Insets: SEM image showing the nanowires being measured by STM probes. The scale bars correspond to 2 µm.

Figure S2: Aspect-ratio measurements of as-produced and passivated Si nanowires by SEM. Passivation of Si nanowires increases the aspect-ratio by decreasing the diameter of as-produced Si nanowires.
Supporting Movie Legend

Supporting Movie 1: Alignment of two individual Si nanowires at different frequencies under slow-rates and demonstration of sorting according to their electrical conductivities.

References
(1) Jones, T. B. Electromechanics of Particles; Cambridge University Press, 2005.