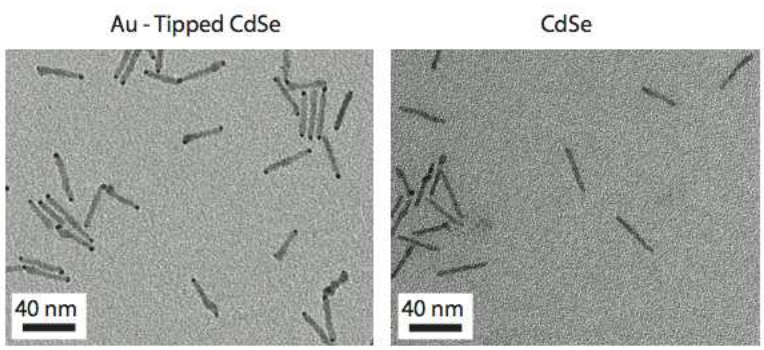
Supplementary Information

Enhanced semiconductor nanocrystal conductance via solution grown contacts

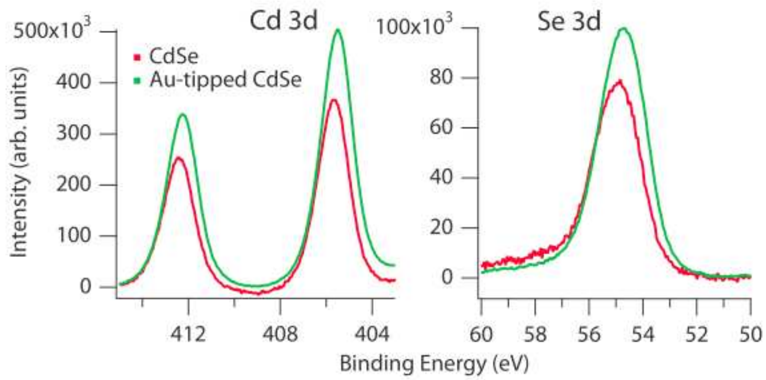
Matthew T. Sheldon[1], Paul-Emile Trudeau[1], Taleb Mokari[2], Lin-Wang Wang[3], and A.Paul Alivisatos[1,4]*

1. University of California, Berkeley, California 94720, USA
2. Molecular Foundry, Materials Sciences Division, Lawrence Berkeley National Laboratory
3. Computational Research Division, Lawrence Berkeley National Laboratory
4. Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

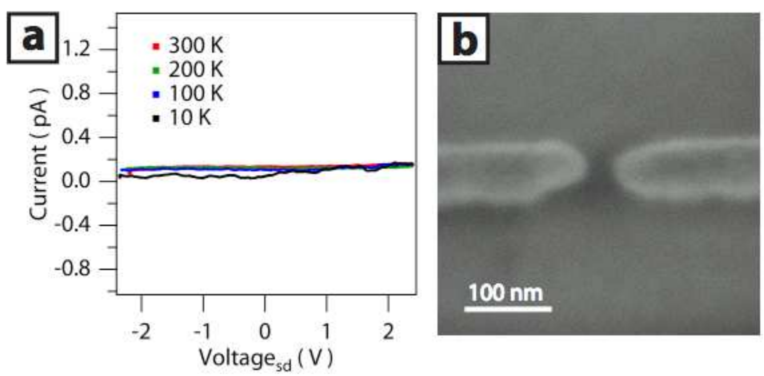
*alivis@uclink4.berkeley.edu



Supplementary Figure 1: Ensemble transmission electron microscopy [TEM]
Statistical analysis of micrographs like those above displaying Au-tipped CdSe nanorods (left) and control CdSe nanorods (right) indicate good sample monodispersity. The nanorods have dimensions 4.8 (± 0.8) by 32 (± 5) nm with 3.4 (± 0.8) nm diameter Au spheres after tip growth.



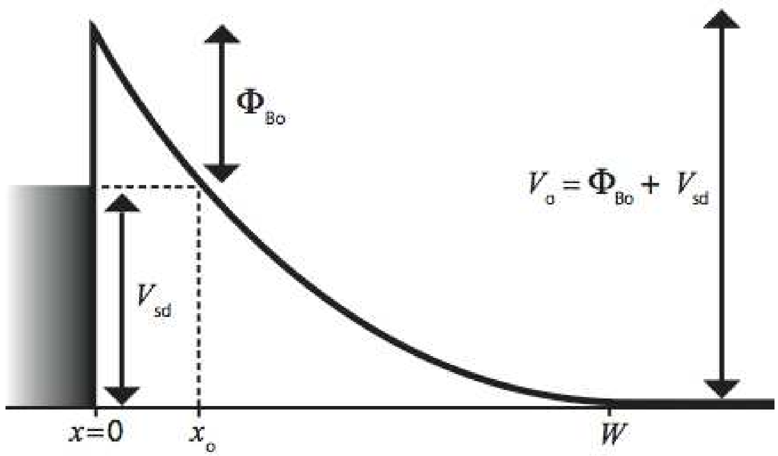
Supplementary Figure 2: X-ray photoelectron spectroscopy The Cd 3d signal (left) and Se 3d signal (right) for an ensemble of CdSe nanorods (red) and Au-tipped CdSe nanorods (green) show no significant difference in binding energy. A peak shift or broadening of ~2 eV would indicate a change in the oxidation state or chemical environment of the Cd or Se atoms present in the Au-tipped CdSe sample.



Supplementary Figure 3: Background current of an empty Au junction (a) There is no current response from an Au junction without a nanorod present, across the temperature range of our study. (b) Scanning electron micrograph [SEM] of a device with no nanorods.

Derivation of Equation (1)

The procedure follows from the general strategy outlined by Sze, with the barrier structure diagramed below. Electrons tunnel from left to right under bias.



N_D = doping density
ε_s = semiconductor permittivity
q = elementary charge
W = depletion width
m = effective mass

Poisson's equation defines the potential as a function of distance from the electrode, x, in terms of the voltage across the contact V_o (=V_{sd}+Φ_0)

$$V(x) = \frac{q}{2\varepsilon_s} N_D (W - x)^2 \tag{S1}$$

where $W = \sqrt{\frac{2\varepsilon_s V_o}{q N_D}}$ (S2)

and $x_o = W - \sqrt{\frac{2\varepsilon_s}{4\pi q N_D} V_{sd}}$ (S3)

The overall current due to tunneling will be equal to:

$$I_{sd} \propto V_{sd} \cdot e^{-2\Gamma} \tag{S4}$$

where Γ is the tunneling phase factor:

$$\Gamma = \int_0^{x_o} k(x)dx = \int_0^{x_o} \sqrt{\frac{2mq}{\hbar^2}\left[\frac{4\pi q N_D}{2\varepsilon_s}(W - x)^2 - V_{sd}\right]}dx \tag{S5}$$

with the definition for the electron wave vector:

$$k(x) = \sqrt{\frac{2mq}{\hbar^2}\left(V(x) - V_{\mathrm{sd}}\right)} \tag{S6}$$

The integral in equation (S5) can be solved by substitution, note that:

$$\int_1^a \sqrt{y^2 - 1}\, dy = \tfrac{1}{2}\left(a\sqrt{a^2 - 1} - b\right) \text{ where } b = \mathrm{ArcCosh}(a) \tag{S7}$$

$$\text{then } \Gamma = \sqrt{\frac{4m\varepsilon_{\mathrm{s}} V_{\mathrm{sd}}^2}{4\pi\hbar^2 N_{\mathrm{D}}}} \int_1^{\sqrt{V_{\mathrm{o}}/V_{\mathrm{sd}}}} \sqrt{y^2 - 1}\, dy \tag{S8}$$

$$\text{giving } \Gamma = \sqrt{\frac{m\varepsilon_{\mathrm{s}}}{\hbar^2 N_{\mathrm{D}}}} \cdot \left[\sqrt{\left(V_{\mathrm{sd}} + \Phi_{\mathrm{o}}\right) \cdot \Phi_{\mathrm{o}}} - V_{\mathrm{sd}} \cdot \mathrm{ArcCosh}\left(\sqrt{\frac{V_{\mathrm{o}}}{V_{\mathrm{sd}}}}\right)\right] \tag{S9}$$

Substitution of equation (S9) for Γ into equation (S4) reproduces the expression for the tunneling current, equation (1), in the main body of the text.