Supporting Information for

Ultrathin Epitaxial Cu@Au Core−Shell Nanowires for Stable Transparent Conductors

Zhiqiang Niu,[†,‡,▽] *Fan Cui,*[†,‡,▽] *Yi Yu,*[†,§] *Nigel Becknell,*[†] *Yuchun Sun,*[†] *Garo Khanarian,*[∥] *Dohyung Kim,*[⊥] *Letian Dou,*[†,‡] *Ahmad Dehestani,*[‡] *Kerstin Schierle-Arndt,*[‡] *and Peidong Yang*[*,†,‡,⊥,#]

[†]Department of Chemistry, University of California, Berkeley, California 94720, United States
[‡]California Research Alliance (CARA), BASF Corporation, Berkeley, California 94720, United States
[§]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States
[∥]BASF Corporation, Union, New Jersey 07083, United States
[⊥]Department of Materials Science and Engineering, University of California, Berkeley, California 94720, United States
[#]Kavli Energy NanoSciences Institute at the University of California, Berkeley, and the Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States

Experimental Details

Optical simulation. All simulations were conducted using the semi-empirical models developed previously for Ag[1] and Cu@*r*-GO core−shell[2] nanowires. Briefly, the transmittance (T) and haze (H) were calculated using the Mie formalism for core−shell rods.[3-5] The optical constants of Cu and Ag, and the diameters of core D_2 and shell D_1 were used as input into the Mie equation to calculate T and H as a function of surface areal coverage ϕ_s using equation A9 and A10 in ref. 1. The calculation also requires an "effective refractive index" for the Fresnel transmission factor for the Cu@Au film on glass. It was found that n_{eff} ~1.1 gave the best fit to the H vs T data, which was reasonable considering that Cu has real index between 0.2 and 1 in the visible wavelength range.[6] No binder was used (i.e the Cu@Au films were in air) and the surface coverage was ϕ_s ~ 0.2–0.4. The sheet resistance R_s of the core−shell nanowire film was calculated using the same approach as for Ag nanowires (equation 18 in ref. 1) but modified to account for the core−shell geometry as two resistors in parallel with resistivities ρ_2 (inner core) and ρ_1 (outer shell), respectively. After some manipulation, the sheet resistance equation becomes:

$$R_s = \frac{C}{\left(\frac{r}{\rho_2}+\frac{1-r}{\rho_1}\right)} \frac{\frac{8}{\pi D_1}}{(\phi_s - \phi_c)^t} \qquad (1)$$

Where $r = \left(\frac{D_2}{D_1}\right)^2$, ϕ_s is the surface areal fraction covered by nanowires, ϕ_c is the critical percolation areal fraction $\phi_c = \frac{18<D_1><L>}{<L^2>}$, L is the length of the nanowires, t is the critical exponent for electrical percolation in 2D networks (t ~ 1.3), and C is a parameter to account for contact resistance R_j between nanowires . When C~1 then R_j ~0.

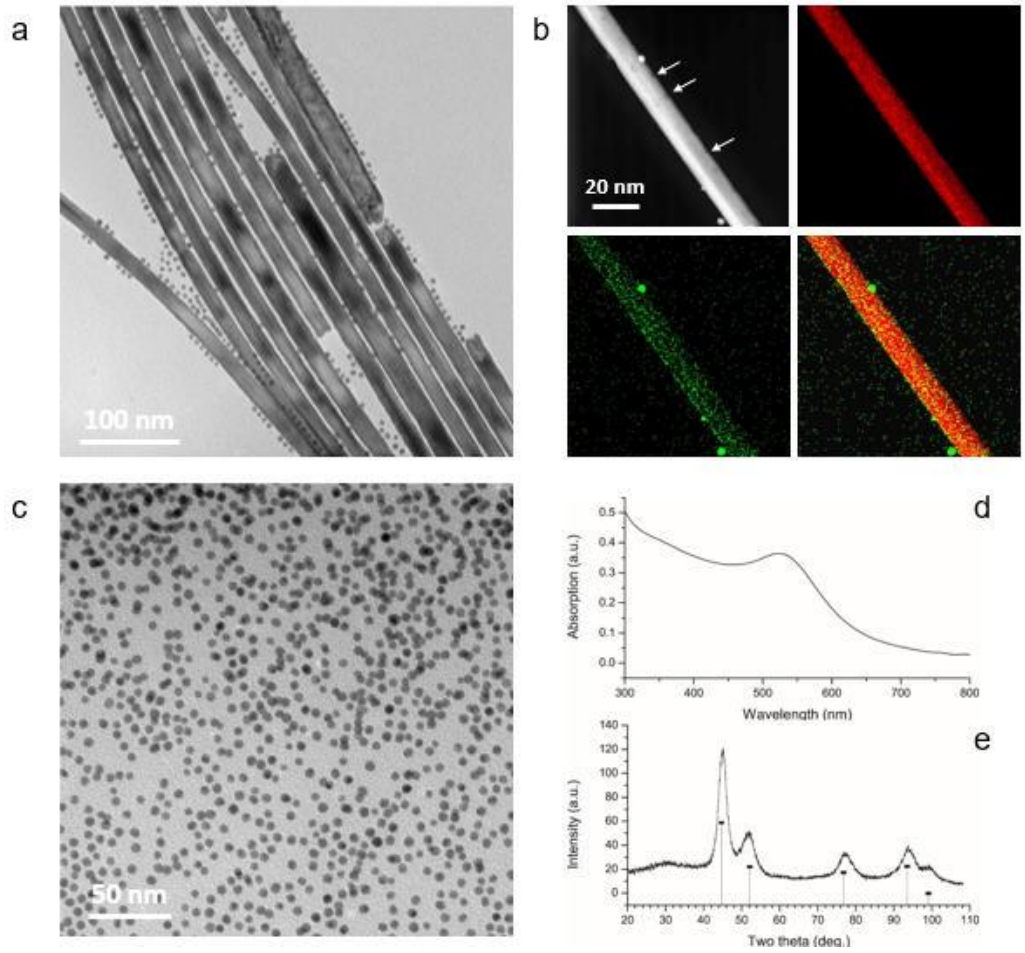

Figure S1. TEM image (**a**) and EDS mapping (**b**) of the product mixture obtained via a fast injection of the oleylamine dispersion of gold(III) chloride trihydrate (Scheme 1, route 1). TEM image (**c**), UV−vis absorption spectrum (**d**) and XRD (**e**) of small nanoparticles separated from the product mixture. The arrows in the HAADF-STEM image (top left in **b**) indicate surface pits on the nanowires.

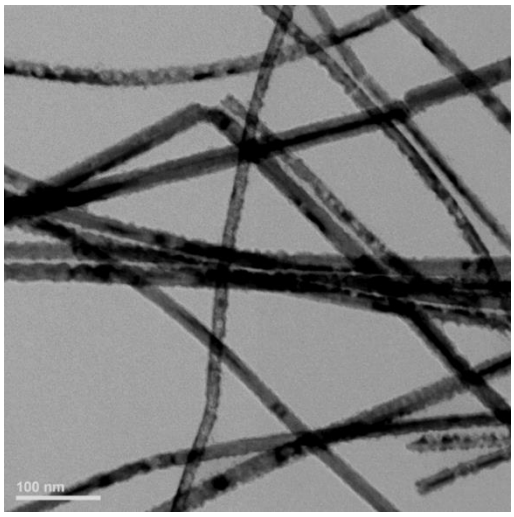

Figure S2. TEM image of the nanowires obtained via a slow injection of the oleylamine dispersion of gold(III) chloride trihydrate (Scheme 1, route 2).

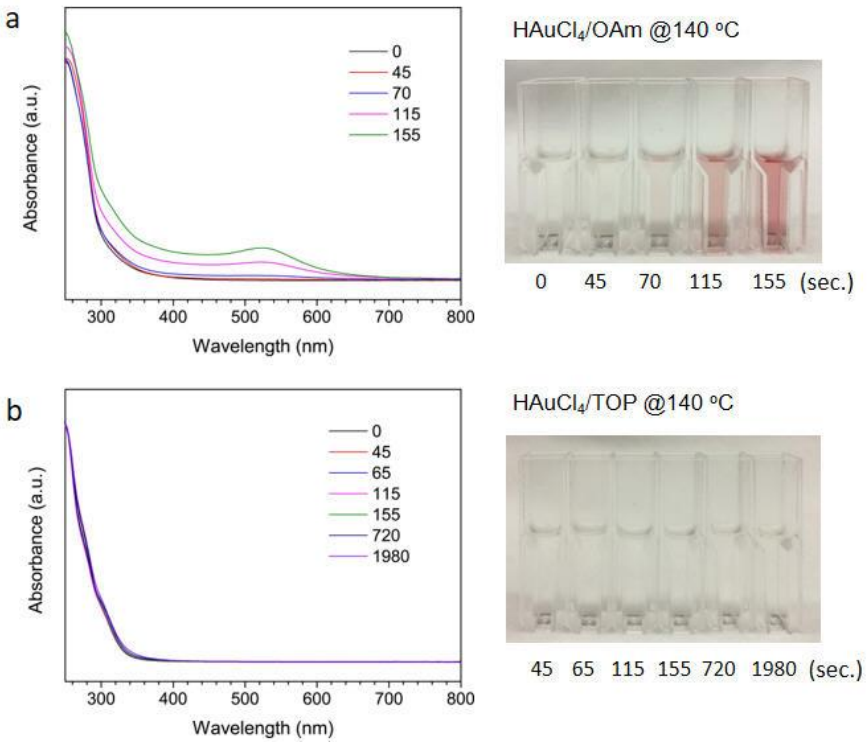

Figure S3. Reduction kinetics studies of gold(III) chloride trihydrate at 140 °C under different ligand environments. UV−vis absorption spectra and corresponding digital images of reaction solutions recorded at different reaction times (second) after injecting the gold(III) chloride trihydrate pre-dispersed in 1 mL of OAm (**a**) and TOP (**b**) into 5 mL of pre-heated OAm.

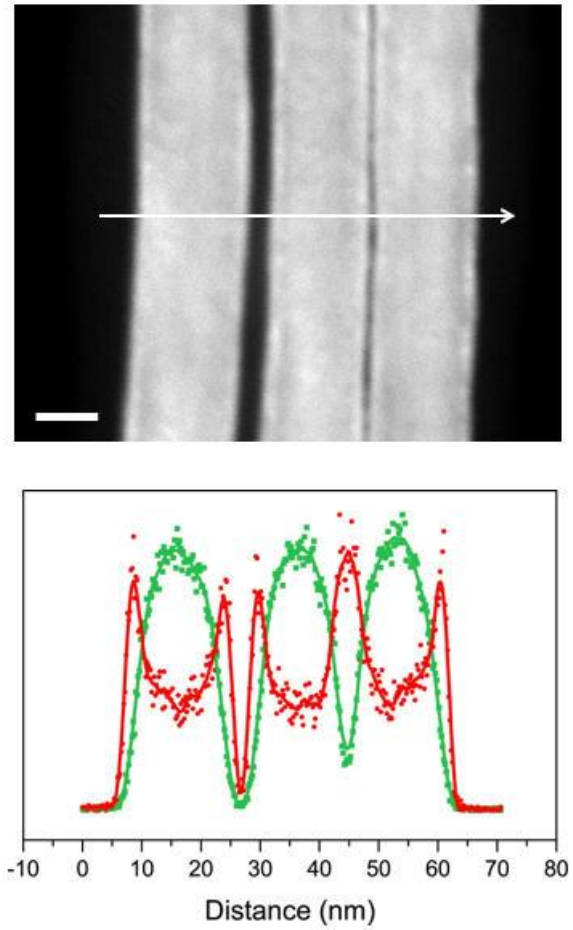

Figure S4. The compositional line profiles of copper (green) and gold (red) across three aligned nanowires. Scale bar: 10 nm.

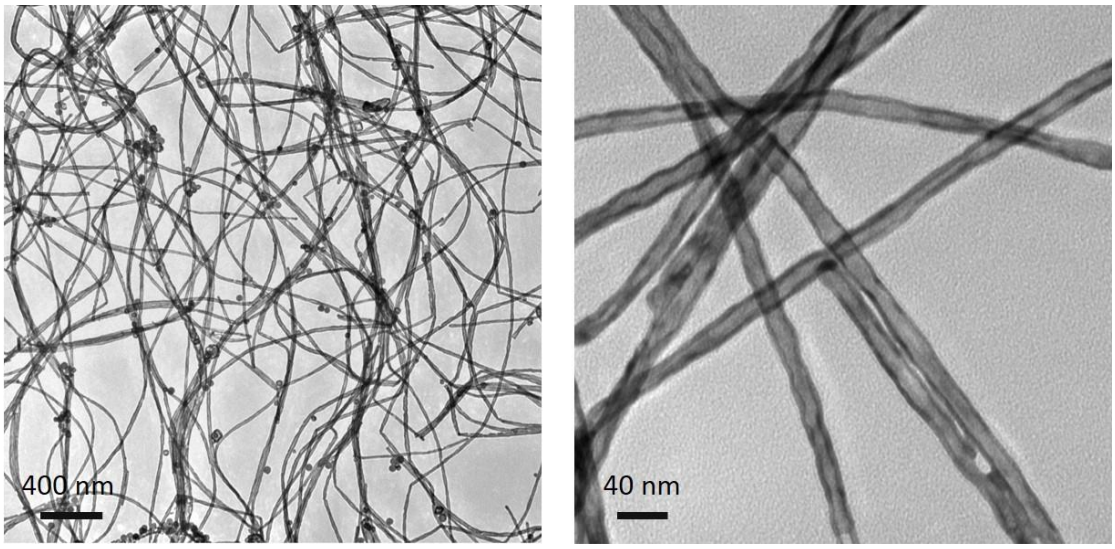

Figure S5. TEM images at different magnifications of the nanotubes produced by acid corrosion of Cu@Au core−shell nanowires.

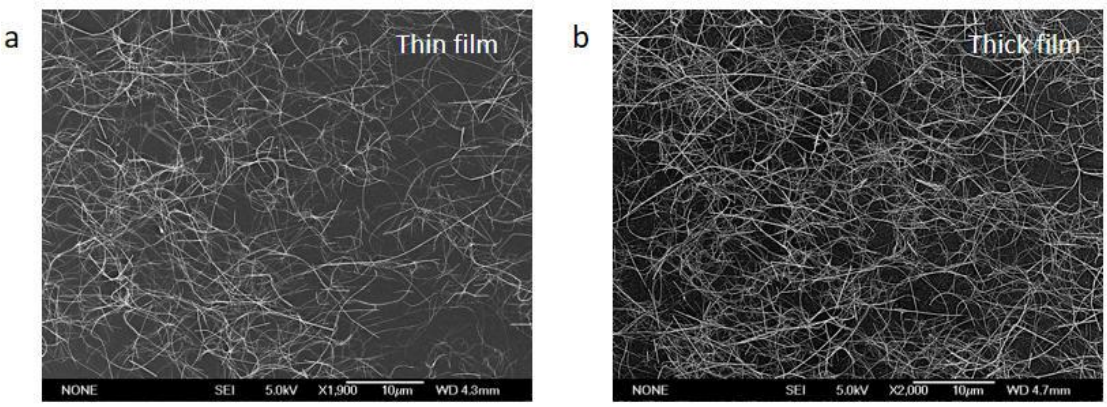

Figure S6. SEM images of transparent conducting films that are made on thin glass slides with different nanowire loadings.

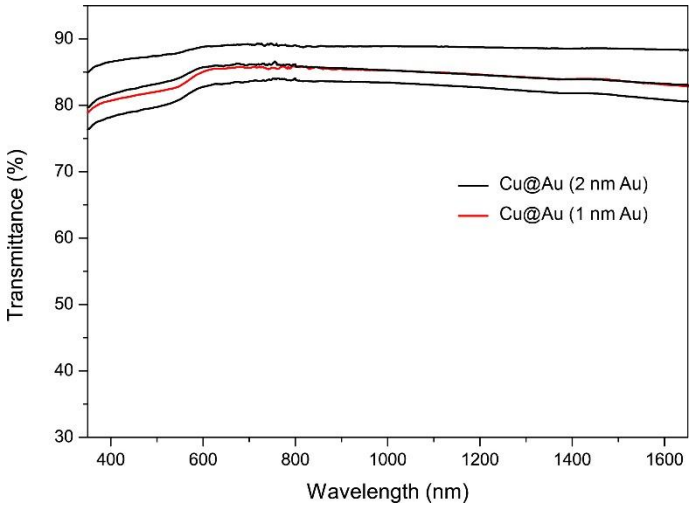

Figure S7. Transmittance spectra of transparent conducting films made from Cu@Au core−shell nanowires. The black lines are all Cu@Au (2 nm Au) with loading amount changed; the red line is Cu@Au (1 nm Au) with a similar loading to one of the black lines.

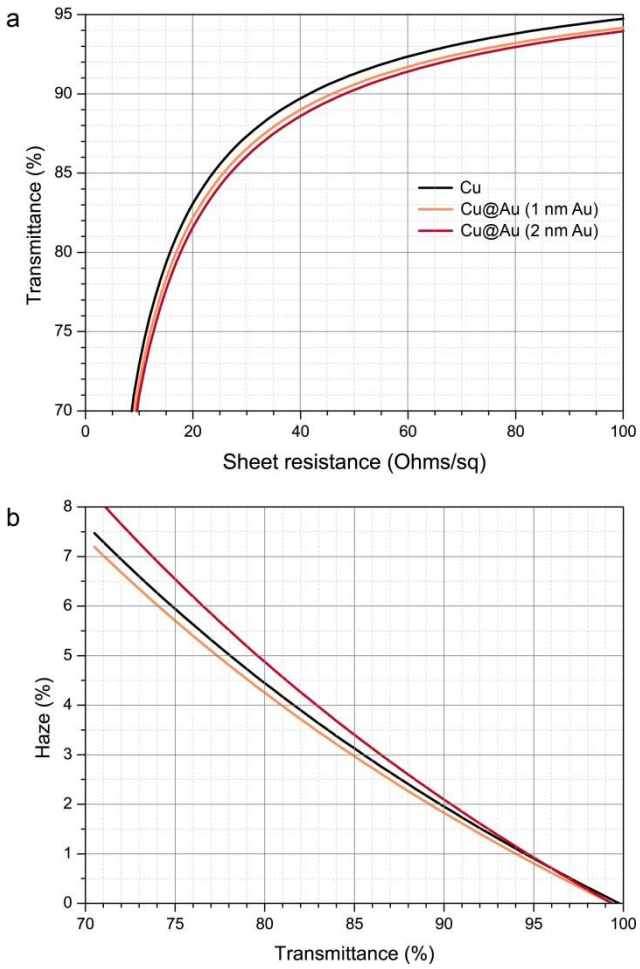

Figure S8. Simulated transmittance versus the sheet resistance (**a**) and simulated haze versus transmittance (**b**) of simplified nanowire structures: Cu (d = 17 nm), Cu@Au (d= 19 nm with 1 nm Au shell), and Cu@Au (d = 21 nm with 2 nm Au shell).

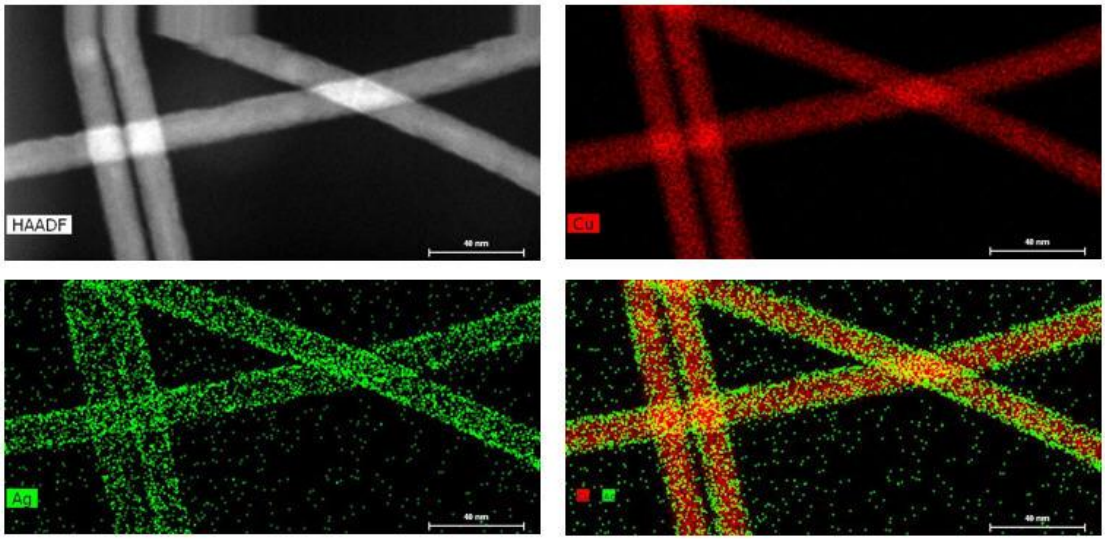

Figure S9. EDS mapping of Cu@Ag nanowires ($Cu_{90}Ag_{10}$). Scale bar: 40 nm.

Reference

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