Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Contacts to solution-synthesized SnS nanoribbons: Dependence of barrier height on metal work function

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Chemicals

Sulfur powder (99.98%) and oleylamine (70%, technical grade) were purchased from Sigma-Aldrich. Tin(II) chloride and tri-*n*-octylphosphine (90%, technical grade) were purchased from Alfa Aesar. Poly(methyl methacrylate) 495 A4 and 950 A4 were purchased from Microchem. Hydrofluoric acid (48%) was purchased from EMD Millipore. All chemicals were used as received.

Synthesis of SnS Nanoribbons

Colloidal nanoribbons of SnS were synthesized using our previously developed high-yield solution route.[1] 1 mmol of elemental sulfur powder was dissolved in 10 mL of oleylamine using a sonic bath, forming an orange solution. The sulfur solution, along with a Teflon stir bar, were charged into a 25 mL three-neck flask. Additionally, this flask was equipped with a glass-coated thermocouple and a Liebig condenser connected to a Schlenk line (ChemGlass) using Tygon tubing. To this reaction solution, 0.5 mmol of tin(II) chloride was added and the reaction flask was placed in a 25 mL heating mantle (Glas-Col) which, along with the thermocouple, was connected to a digital temperature controller (Gemini, J-KEM Scientific). The remaining neck was sealed with a glass stopper and the vessel was evacuated. While stirring, the solution was heated to 120 °C and maintained there under vacuum for 20 minutes to remove residual water. The reaction was then put under an argon blanket and the temperature was raised to 180 °C, resulting in the darkening of the solution from orange to dark brown as colloidal SnS nanoribbons formed in solution. After maintaining the temperature for 1 hour, the reaction was quenched in cold water. The colloidal nanocrystal product was separated from the reaction solution by adding 30 mL of ethanol and centrifuging at 5000 rpm for 1 minute. The yellow supernatant was decanted and the precipitated nanoribbons were redispersed in toluene and centrifuged a second time at 3000 rpm for 1 minute. After decanting the clear supernatant, the product was redispersed in toluene and centrifuged for a third time at 2000 rpm for 1 minute. After decanting the light brown supernatant, the precipitated nanocrystals were redispersed in 4 mL of neat toluene with the assistance of a sonic bath. If long-term storage was desired, two drops of oleylamine and 1 drop of tri-*n*-octylphosphine was added to aid with colloidal stability. Microscopy analysis revealed that the resulting 2D nanoribbons had an average length of 2.8 μm, width of 0.5 μm, and thickness of ~17-20 nm. The SnS nanoribbons are single-crystalline, with a preferred orientation towards the SnS(100) crystallographic facet when dropcast onto a substrate.[1] The in-plane anisotropy of this crystal was manifest in that the length of the nanoribbon corresponded to the zigzag direction of the SnS structure and the width to the armchair arrangement, as confirmed by diffraction studies. Elemental analysis indicated the atomic ratio of Sn and S was near stoichiometric.[1] Nanoribbon solutions were diluted with toluene prior to device fabrication.

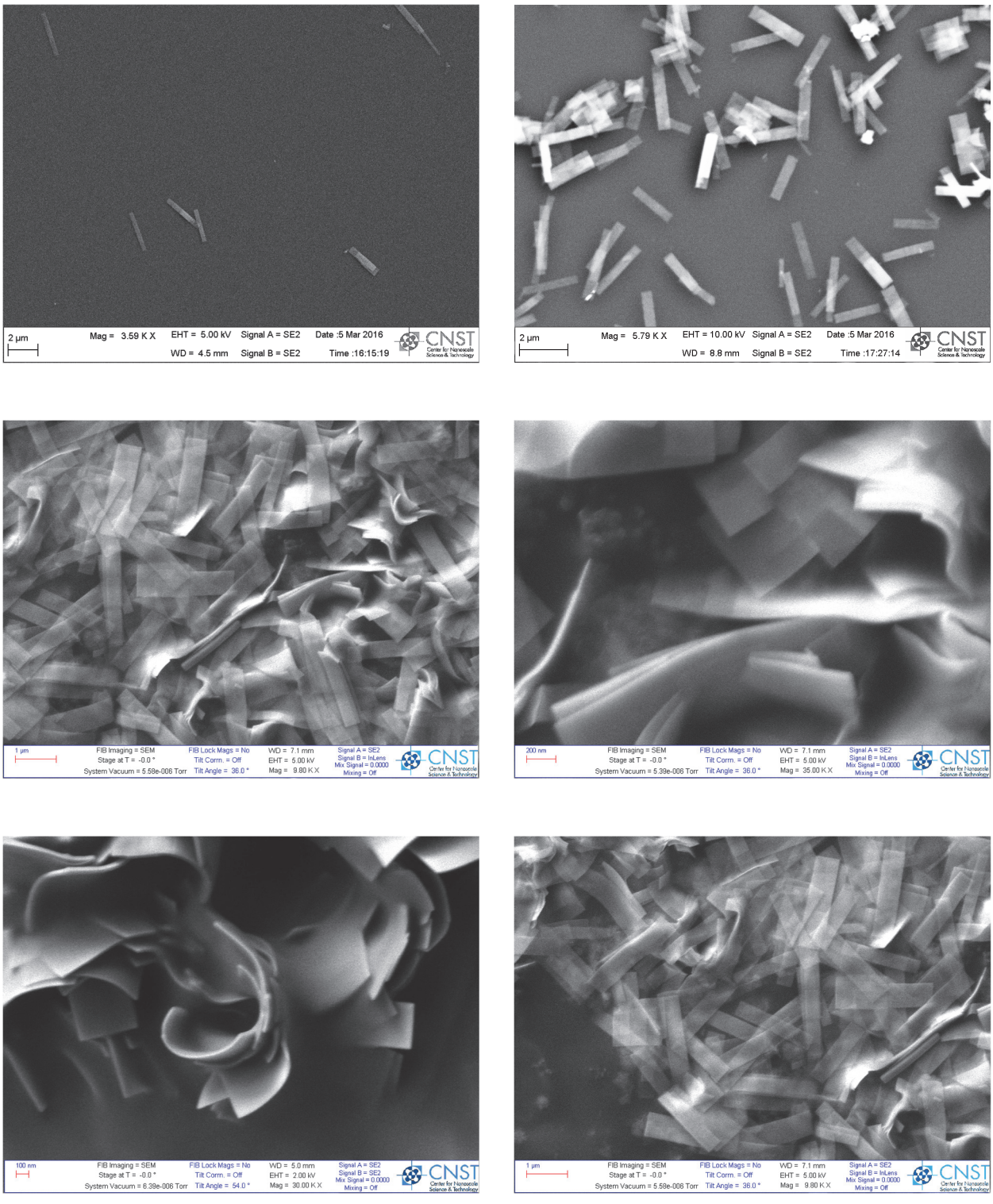


Figure S1. Additional SEM images of deposited SnS nanoribbons.

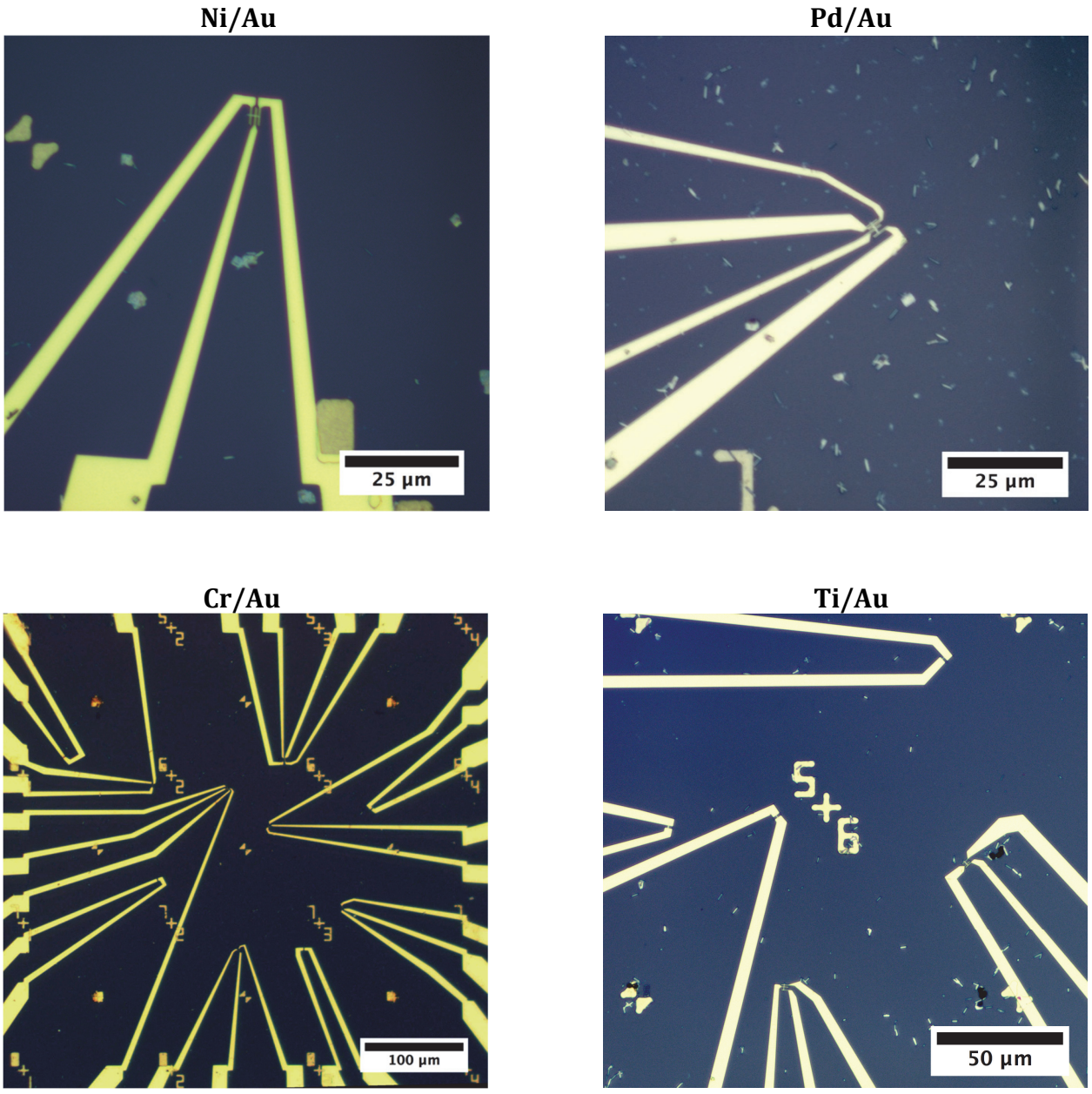


Figure S2. Additional optical microscope images of SnS nanoribbon devices.

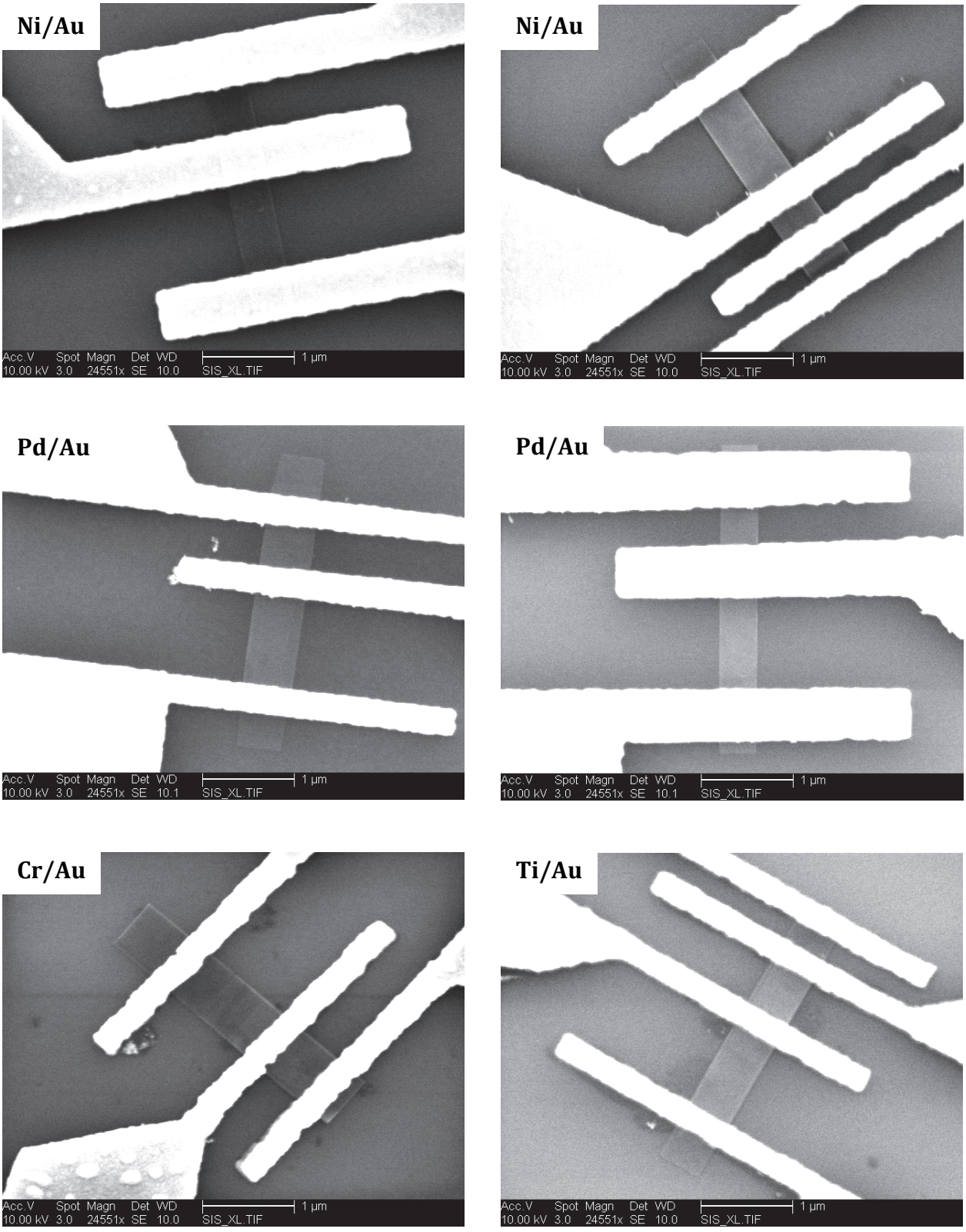
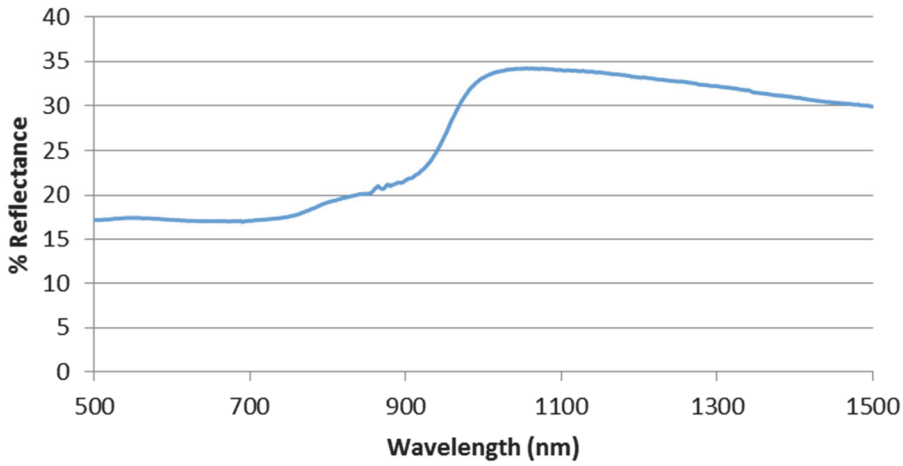


Figure S3. Additional SEM images of SnS nanoribbon devices.

(a)



(b)

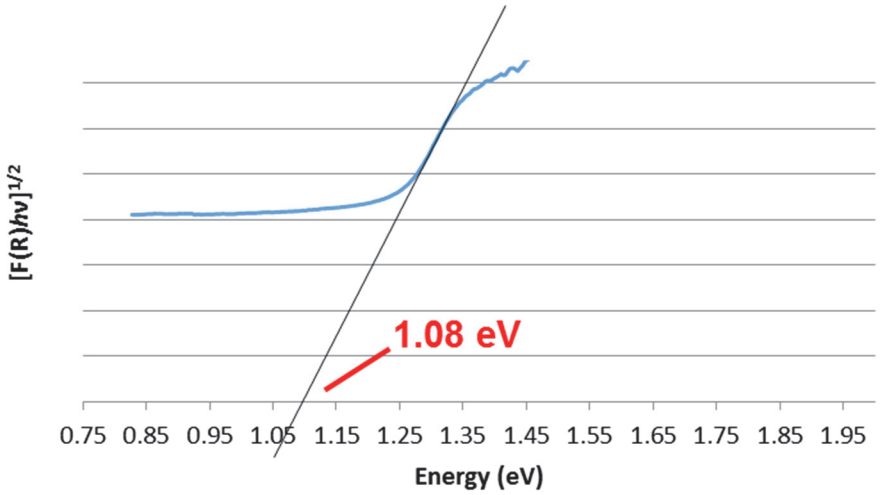


Figure S4. (a) Diffuse reflectance spectrum collected from dropcast SnS nanoribbons and (b) the corresponding Tauc plot of the Kubelka-Munk function for calculation of the indirect band gap.[2]

Derivation of Equation 1

The current, I, through back-to back Schottky diodes 1 and 2 can be described by the thermionic emission equation[3]

$$I_1 = I_{01}\left[1 - \exp\left(-\frac{qV_1}{kT}\right)\right] \qquad \text{(S1a)}$$

$$I_2 = I_{02}\left[\exp\left(\frac{qV_2}{kT}\right) - 1\right], \qquad \text{(S1b)}$$

where q is the elementary charge, k is Boltzmann's constant, $V_{1,2}$ is the voltage through each diode, and $I_{01,02}$ are the saturation currents defined in Eq. 2a,b. The subscripts refer to diodes 1 and 2, respectively.

Current through each diode is equivalent ($I_1 = -I_2 = I$), and the voltage drop across each diode is given as

$$V_1 = -\frac{kT}{q}\ln\left(1 - \frac{I}{I_{01}}\right) \qquad \text{(S2)}$$

$$V_2 = \frac{kT}{q}\ln\left(1 + \frac{I}{I_{02}}\right). \qquad \text{(S3)}$$

By summing the voltages and solving for I, the total current through the device is

$$I = \frac{2I_{01}I_{02}\sinh\left(\frac{qV}{2kT}\right)}{I_{01}\exp\left(-\frac{qV}{2kT}\right) + I_{02}\exp\left(\frac{qV}{2kT}\right)}, \quad \text{(S4)}$$

where V is the applied voltage.

References

1. A. J. Biacchi, S. T. Le, B. G. Alberding, J. A. Hagmann, S. J. Pookpanratana, E. J. Heilweil, C. A. Richter and A. R. Hight Walker, *submitted*.
2. J. Tauc, R. Grigorovici, and A. Vancu, *Phys. Status Solidi*, 1966, **15**, 627-637.
3. D. K. Schroder, in *Semiconductor Material and Device Characterization*, J. Wiley & Sons, Hoboken, NJ, 3rd edn, 2006, ch. 3, pp. 127-184.