Supporting Information

Band-to-Band Tunneling Dominated Thermo-Enhanced Field Electron Emission from p-Si/ZnO Nano-Emitters

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The effective carrier concentration of the individual ZnO nano-pillar was derived from the electrical conductivity data. In our early work,[1] two-terminal electric-conductance measurements were carried out using a modified SEM, which is equipped with a precisely manipulated (2 nm per step) probe (gold coated tungsten tip). A thin layer of aluminum was coated on the backside of the Si chip for achieving an ohmic-contact between the sample and the holder. A well electric contact was obtained by "melting" the ZnO apex and making it soldered with the probe by current conditioning. In the high voltage region (also with high current), the voltage drop on the bodies of both the Si and ZnO nano-pillars become dominated, while that on the Si/ZnO hetero-junction is weak.[2, 3] Therefore, the total resistance of the Si/ZnO nano-emitter could be obtained by differentiating the I-V curve, i.e., R=dV/dI. To eliminate the effect of the hetero-junction, the linear fitting was performed using the data with higher current section for each I-V curves (Figure S1). The total resistance (R_{Total}) of the Si/ZnO nano-emitter was derived from the slope of the fitting curve. The resistance of the Si nano-pillar (R_{Si}) was calculated considering the geometrical profile, i.e., 1.9 kΩ. We regard the difference between the R_{Total} and R_{Si} as that of the ZnO nano-pillar. Further considering the geometrical profile of the ZnO nano-pillar, the electrical conductivity σ can be derived. Finally, the effective carrier concentration (i.e., n) of ZnO can be derived using the Ohm's law,

$$n = \sigma / \mu q .$$

Herein, the carrier mobility of ZnO μ=200 $cm^2 \cdot V^{-1} \cdot s^{-1}$,[4] and the electron charge $q=1.602\times10^{-19}$ C. The calculation results are summarized in Table S1. The data of the effective carrier concentrations derived from the I-V curves (from 6 nanowires) are in the ~10^{16} cm^{-3} order of magnitude, which are well consistent with those in earlier literatures.[5, 6]

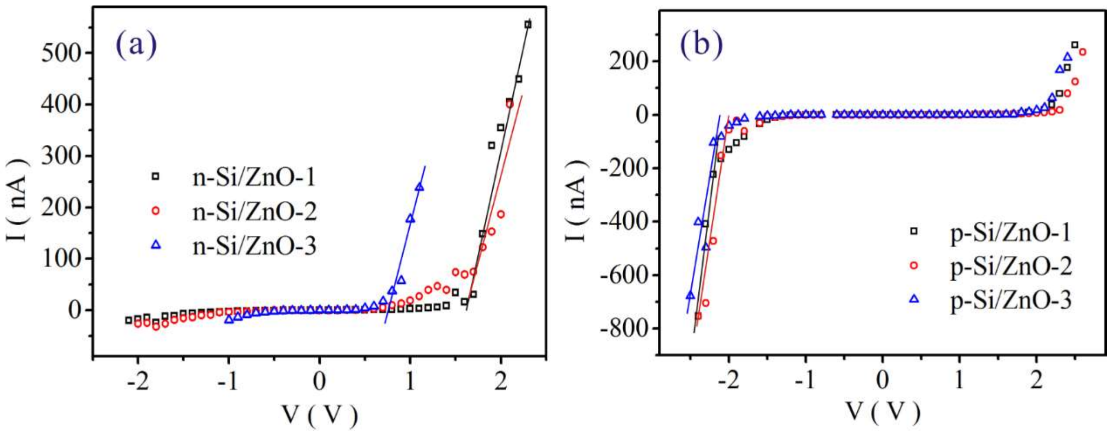

Figure S1. Experimental data of the electric conductance I-V curves for the individual (a) n-Si/ZnO and (b) p-Si/ZnO nano-emitters. (Reproduced from the insets of Figure 4 (a) and (b) in Ref [1].) The straight lines are the linear fitting curves in the high voltage regions.

Table S1. Relevant parameters extracting from the electric conductance I-V curves.

Label	Total resistance of Si/ZnO (kΩ)	Resistance of ZnO (kΩ)	Conductivity of ZnO ($\Omega^{-1}\cdot cm^{-1}$)	Effective carrier concentration of ZnO (cm^{-3})
n-Si/ZnO-1	1238	1236	0.613	1.91×10^{16}
n-Si/ZnO-2	1398	1396	0.543	1.70×10^{16}
n-Si/ZnO-3	1104	1102	0.690	2.15×10^{16}
p-Si/ZnO-1	378	376	2.020	6.31×10^{16}
p-Si/ZnO-2	513	511	1.486	4.64×10^{16}
p-Si/ZnO-3	614	612	1.242	3.88×10^{16}

Note: Geometrical parameters employed in the calculation: the Si nano-pillar with 140 nm top diameter, 160 nm bottom diameter and 650 nm in length. The conductivity of Si is 0.005 Ω·cm. The ZnO nano-pillar with 60 nm top diameter, 140 nm bottom diameter and 500 nm in length.

References

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