Gated Si Tip Field Electron Emitter with Integrated Nano-Conduction-Channel

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Si tip is a promising field emission cathode for vacuum nano-electronics application. Although significant progress has been achieved, the improvement in the device uniformity and reliability are still open issues. One of the promising ways to address these issues is to integrate the current-limited element with the individual tip [1]. Here, we report a featured Si tip structure with an integrated nano-conduction-channel as a current limiter (Fig 1(a)), which has improved reliability while maintaining a low driving voltage. The tip resistance has significant dependence on the channel diameter, i.e., 12.9, 5.53×10^{-1}, 1.37×10^{-2} GΩ for the tips with channel diameters of 70, 80 and 120 nm, respectively [2]. The depletion layer induced by surface state has the main contribution on the tip resistance. Fig. 1(b) shows the typical field emission characteristics of the gated devices with the 70-nm-channel. A typical current density of ~8.9 mA/cm^2 (8 μA at 85 V) was obtained. The Fowler-Nordheim (F-N) plots are well straight lines, suggesting a weak current limited effect. By considering a total emission current range of 2~8 μA for a 40×40 array, the average emission current for each individual tip is 1.25~5 nA. Thus, a 12.9 GΩ tip resistance would cause a 16~64.5 V bias drop as a rough estimate. The voltage drop would cause the saturation in the F-N plot, which is not in consistent with the experimental result indicted in Fig. 1(b). Further experiments demonstrated that the nano-channel could not only limit the current but also confine the Joule heat to the tip apex. We proposed that the channel limits both the electric and thermal conduction. The tip temperature would significantly increase during the field emission, which would enhance the electron tunneling. Meanwhile, the current limited effect from the channel impedes the uncontrollable increase of the emission current to avoid the vacuum breakdown event. Both the thermal enhanced field emission and the current limited effect result in a linear F-N plot.

References:

[1] S. A. Guerrera, L. F. Velásquez-García, and A. I. Akinwande. IEEE Transaction on Electron Devices **58,** 2524 (2012).
[2] Z X Pan, J C She, S Z Deng, and N S Xu, The Technical Digest of 27th IVNC, Engelberg, Switzerland, 2014.

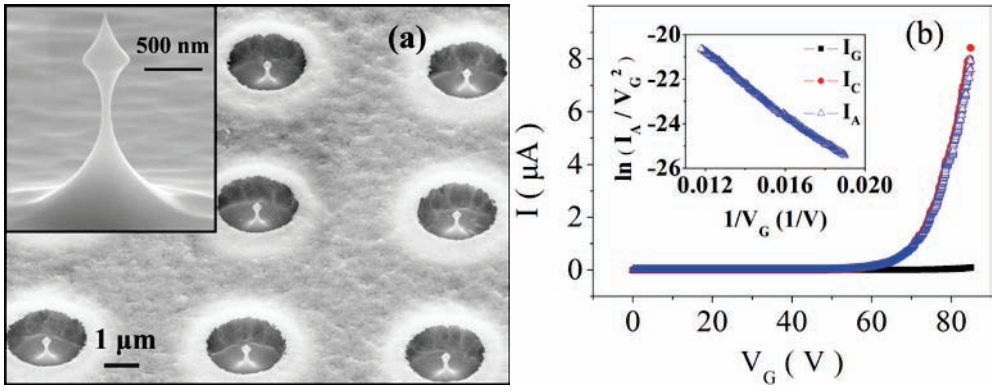

FIG. 1. (a) The typical SEM image (45° tilt-view) of the gated Si field emitter array (40×40). The inset is the high-resolution SEM image of a representative tip (85° tilt-view). The typical length of the nano-channel is 170 nm. The gate aperture is 2.5 μm. (b) The typical field emission I-V_G curves of the gated Si emitter with nano-channel. Here I_A is the anode current, I_G is the gate current, while I_C for the cathode current. The inset is the corresponding F-N plots.