Quantum Interference Effects in the Nanotriode

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For several years there has been much interest in vacuum microelectronic devices[1] primarily due to their unique properties: ballistic electron transport, high current densities, and operating characteristics effectively independent of radiation and temperature. These result in a wide range of potential applications including high frequency devices, sensors, and high brightness electron sources for electron-beam applications. In the new area of vacuum nanoelectronics, where devices are scaled to nanometer sizes, it is possible to fabricate devices that operate at voltages approaching those of solid-state transistors. Further, emission from nanometer scale cathodes show characteristics associated with their atomic size[2]: narrow energy spread, very high brightness and coherence[3]. Vacuum nanoelectronics also introduces the possibility of exploiting quantum effects in devices as, in contrast to semiconductor nanostructures, the electron wave propagates in vacuum thus eliminating inelastic scattering and hence ensuring that the phase coherence of the electron wave is preserved, even at room temperature.

Studies of these quantum interference effects were performed using a three element device, the nanotriode[4,5] (see figure 1), in which electrons are emitted by Fowler-Nordheim tunneling from metal nanopillars, with radii of about 1nm, into a vacuum chamber sealed by an integrated anode. The gate electrode controls the field emission current and the dimensions of the whole structure is about 100nm in both the horizontal and vertical directions.

Typical room-temperature, current-voltage characteristics of the nanotriode are shown in figure 2. The turn-on voltage for field emission is about 8V and emission currents of up to 10nA can be obtained. The inset on figure 2 shows the Fowler-Nordheim plot at an anode voltage of 11V and indicates conduction through a field emission process. Experiments performed at temperatures of 20K show a reduction in the leakage currents across the dielectric layers, however, the field emission current is not significantly different to that measured at room temperature.

The current-voltage curves also show the presence of structure superimposed on the field-emitted current that persists even at 20K. These fluctuations are time-independent, repeatable and remarkably consistent at all temperatures. The fluctuations become more apparent when displayed as transconductance, as in figure 3. That these features are repeatable to each nanotriode independent of temperature implies that the structure is an inherent property of the device. Further, as these fluctuations are observed only in the encapsulated nanotriode and not for example, in a diode structure, this suggests that the fluctuations do not arise from a resonant tunneling effect, as this is common to both devices, but in the short, well-defined electron trajectory from the nanopillar tip to the anode. It is proposed that the origin of this structure is a quantum-interference effect between the electron wave function in the tip of the nanopillar emitter and that of the anode, such that when standing-wave conditions in the potential between the nanotip and anode are fulfilled, the tunneling probability is enhanced.

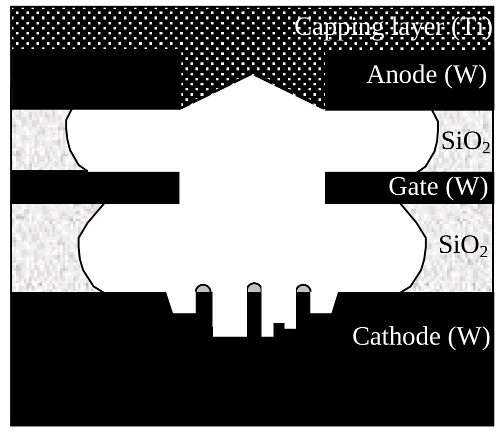

Figure 1: Schematic diagram of the encapsulated vacuum nanotriode. The pillars on the cathode surface are not to scale.

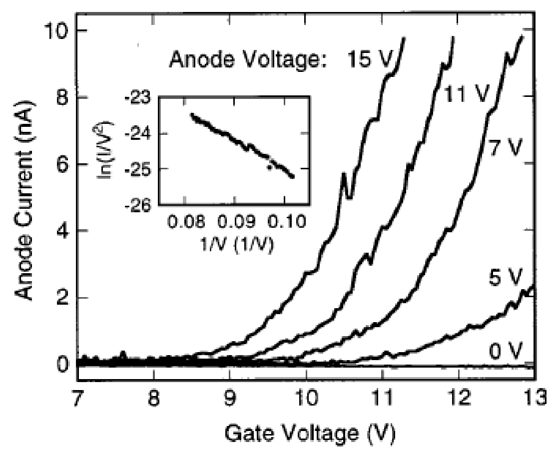

Figure 2: Typical room-temperature, voltage-current characteristics of an encapsulated nanotriode. Inset: Fowler-Nordheim plot [$\ln(I/V^2)$ Vs V^{-1}] for an anode voltage of 11V.

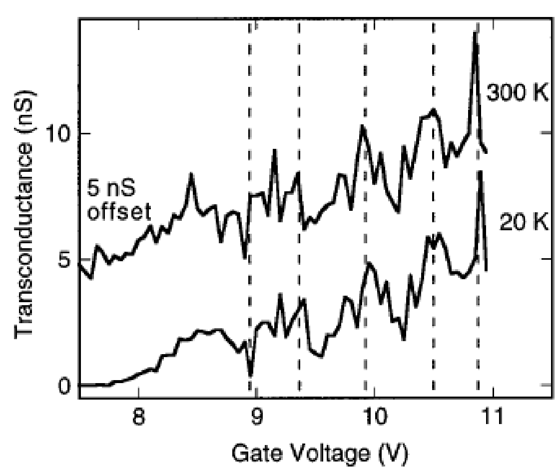

Figure 3: Transconductance (smoothed) at 300K and 20K of an encapsulated nanotriode. The dashed lines indicate features on both curves that coincide.

References

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