Fowler-Nordheim Current Saturation in Integrated Field-emission Diode

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Saturation of Fowler-Nordheim field emission current at high electric fields has been observed in CMOS process-compatible integrated field-emission diodes fabricated using nanostructured silicon cathodes. The silicon nanostructures have atomically sharp tips (height ~ 10 nm, density ~ 10 μm^{-2}) and are self-assembled on silicon substrate that act as the field emission sites for the diodes. They are formed because of thermal decomposition of native oxide during electron beam annealing (EBA) which also promotes nanostructure growth via adatom diffusion and nucleation at kinetically favourable sites [1]. The field emission diodes have been fabricated in order to integrate better device characteristics, such as higher speed, higher current density, higher radiation and temperature insensitivities that field emission offers [2] into mature silicon process technology.

The devices were fabricated on phosphorus-doped 20-30 Ω·cm n-type silicon (100) substrates. 300 nm thermal oxide grown over silicon was patterned, and HF etched for the cathode contacts. Arsenic ions (dose 2×10^{14} cm^{-2}) were implanted with 55 keV in the contact areas creating an arsenic concentration profile that intersects with the surface. A 90 nm thick tungsten layer was sputter deposited over the oxide, patterned with anode and cathode definition and reactive ion etched in SF_6. The anode area was further patterned with arrays of small circles and squares of 5, 10, and 20 μm diameters. A reactive ion etch through the metal was performed to reach the oxide and then wet etch was carried through the oxide to reach the silicon surface to define the area for nanostructure growth. Finally, EBA at 1000 ± 0.1 °C for 15 s with ± 5 $°C{\cdot}s^{-1}$ ramp up and down completed the fabrication process with the growth of nanostructures on the defined open silicon areas as well as activation of the implanted arsenic ions below the cathode contact areas.

Electrical measurements performed in an air ambient inside a shielded probe station using a Hewlett Packard HP-4155A parameter analyser showed ideality factor n of about 2.7, field enhancement factor β of about 5×10^6 cm^{-1} and silicon effective barrier height Φ_{eff} of about 0.17 eV. n was extracted from the slope of the logarithmic linear fit of Schottky emission at low fields. A, Φ_{eff}, and β were found from simultaneously solving relations given by the intercept of the Schottky emission fit and the slope and intercept of the linear $\ln(I/V^2)$ versus $1/V$ fit (Fowler-Nordheim plot) [3].

Saturation of Fowler-Nordheim current was observed above applied voltage of 2 V (field of 6.67×10^4 $V{\cdot}cm^{-1}$) or local field of 1×10^7 $V{\cdot}cm^{-1}$. Possibilities of limited electron supply due to finite electron density and electron velocity saturation in semiconductor and reverse field emission for this result are explored. The existence of current saturation behaviour provides an advantage in applications where an added current limiting resistor in series otherwise would have been required along with the device.

References

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