Atomic force microscopy study of field emission from a single silicon nanotip into a quasi-vacuum (air) medium at the nanoscale

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The field emission current from a nanoscale silicon tip were measured in quasi-vacuum (air) conditions by atomic force microscopy (AFM) with a 10 nm gap between the tip and the AFM probe. It was found that, when the applied voltage varies up to 10 V, the maximum current from a single nanocathode reaches 10 nA. The value of the field enhancement factor of a silicon nanocathode is almost 10 times higher than the theoretical value assumed for the given geometry of the AFM probe and silicon nanotip. This indicates the need to take into account quantum-size effects near the emitter surface, in particular, distortion of the potential barrier due to the penetration of an electric field into the surface region of the emitter when calculating the field emission current. In this vein the development of new theoretical approaches beyond the F-N theory is required.

INTRODUCTION

Nowadays, vacuum nanoelectronics, as a possible alternative to modern solid-state electronics, is of considerable interest, which is due to its ability to operate at high temperatures and in radiation harsh environments, as well as an operation speed of vacuum nanoelectronic devices in the THz range, since there are almost no collisions during ballistic transport of electrons through the vacuum conduction channel. On the contrary, the scattering of charge carriers on the crystal lattice of semiconductor leads to undesirable heating of the structure and the appearance of parasitic defects in the channel, which prevents further scaling of semiconductor electronics. One of the possible solutions is the integration of field-electron emission effects observed in a nanoscale vacuum channel with silicon technology, which has recently been successfully demonstrated by creating prototypes of a new class of nanoscale vacuum channel transistors [1]. Despite the progress achieved in this direction, however, the physics of field emission at the nanoscale with a channel length of 10 nm and below is still poorly studied.

EXPERIMENT AND THEORY: DESCRIPTION

Using the AFM Smart SPM (AIST-NT), we measured in quasi-vacuum conditions (air) the I-V characteristics of a single silicon tip taken from an array of point field emitters, which we previously fabricated using standard operations of silicon technology [2]. The I-V characteristics were measured at an anode voltage V_A varied in the range from 0 V to 10 V with a double current passing cycle at the fixed distance d_S between the tip and the AFM probe. For an empirical evaluation of the field enhancement factor $\beta_{eff} = Ed_S / V_A$ by the slope S of the measured I-V characteristics, the standard F-N formula was used, resulting in $\beta_{eff} = -B_0\varphi^{3/2} d_S / S$, where $B_0 = (4/3\hbar)\sqrt{2m_e}$, $\hbar$ is Planck's constant, m_e is the electron mass, φ is the electron affinity of the silicon.

RESULTS AND DISCUSSION

Figure 1 demonstrates I-V characteristics of a silicon nanotip at a distance $d_S = 10nm$. As it can be seen from the graph, the amplitude of the emission current increases to 10 nA at a voltage of 10 V. It was found that $S = -4.274\,[A/V]$, as a result of which the field enhancement factor $\beta_{eff} = 13.27$ was obtained for the given value of electron affinity $\varphi = 4.1eV$ for silicon.

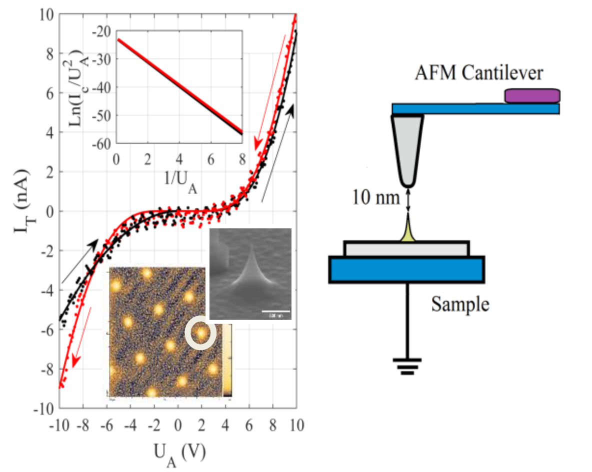

Fig. 1 The I-V characteristics of a Si nanotip from an array of field emitters measuring by AFM ($d_S = 10nm$)

This value is an order of magnitude less than the theoretically calculated for a given system (about 1.5).

CONCLUSION

It can be concluded that quantum-size effects occur at these distances, affecting the emission current, which should be taken into account at the nanoscale [3].

REFERENCES

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