Fabrication of Micrometer-Sized Conical Field Emitters Using Femtosecond Laser-Assisted Etching of Silicon

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ABSTRACT

Arrays of sharp, conical microstructures were obtained by structuring the surface of a silicon wafer using femtosecond laser-assisted etching. Analysis of the arrays shows high, stable field emission without any further processing steps and turn-on fields as low as 1.3 V/μm.

INTRODUCTION

Field-emission arrays have been extensively investigated for device applications such as flat panel displays, electron multipliers and microelectronics. The use of silicon structures as emitters is especially attractive due to the low cost and availability of silicon. Because of the potential for efficient and inexpensive field emission, many fabrication techniques have been reported for making micron-sized silicon-tip arrays but they typically involve intricate processing and preparation such as multiple photolithography, etching, and oxidation steps [1,2]. Previously, our group reported the formation of sharp, micron-sized conical structures in quasi-ordered arrays after irradiating a silicon surface with hundreds of femtosecond-laser pulses in an atmosphere of SF_6 [3,4]. Figure 1 shows a scanning electron micrograph image of an array of microstructures formed in this manner. Emission currents suitable for applications and low turn-on fields are achieved with no further processing beyond the laser irradiation required to form our microstructures. We report on the field emission properties of these conical microstructures through analysis of the current-voltage characteristics and the Fowler-Nordheim relation[5].

EXPERIMENT

We irradiate a Si(111) surface with a train of 800 nm, 100 fs laser pulses in the presence of SF_6. The result of this irradiation is a quasi-ordered array of conical microstructures that form spontaneously, without the use of masks. The structures are 10-12 μm tall with a spacing of 4-6 μm and a tip with radius of curvature of about 250 nm. We formed microstructures over a 2×2 mm^2 area of an n-type silicon (800–1200 $\Omega \bullet$ cm) wafer. We then measure the current-voltage characteristics for an anode-cathode separation of 20 μm and applied voltages ranging from 0 to 1000 V.

RESULTS

The current-voltage characteristics are for potential differences up to 100 V are shown in Figure 2. The field required to produce an emission current density of 1 nA/mm^2, is 1.3 V/μm. We have obtained emission currents up to .5 mA/mm^2 at an applied field of 50 V/μm. The structures are robust and continue to produce field emission after being left in air for several weeks. Plots of the Fowler-Nordheim relation show two regions with linear behavior for potential differences of less than 100 V. Above 100 V the use of a series resistor in the protection circuit for the picoammeter results in an ohmic current-voltage relationship.

CONCLUSIONS

This novel method of creating silicon field emitters produced stable emitters with high emission currents and low-turn on fields without any further processing beyond laser irradiation. We plan to examine the effect of varying parameters such as microstructure height and substrate thickness in order to achieve lower turn-on fields and even higher emission currents. In addition, we are investigating to what degree the impurities and defects introduced during the microstructure formation are responsible for the high field emission observed.

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REFERENCES

[1] S.E. Huq, C.H. Grayer, S.W. Moon, P.D. Prewett, *Materials Science and Engineering B* **51**, 150-153(1998)
[2] C.W. Oh, C.G. Lee, B.G. Park, and J.D. Lee, *J. Vac. Sci. Technol. B* **16**, 765-769(1998)
[3] T.H. Her, R.J. Finlay, C. Wu, S. Deliwala, and E. Mazur, *Appl. Phys. Lett.* **73**, 1673-1675
[4] T.H. Her, R.J. Finlay, C. Wu., and E. Mazur, *Appl. Phys. A* **70**, 383-385(2000)
[5] R.H. Fowler, D.L. Nordheim, *Proc. R. Soc. London A* **119,** 173 (1928)

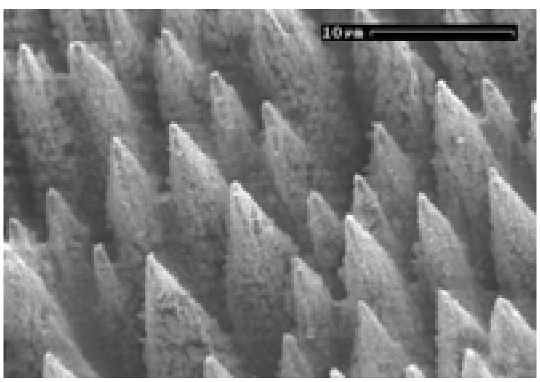

Fig. 1 Scanning electron micrograph of conical microstructures

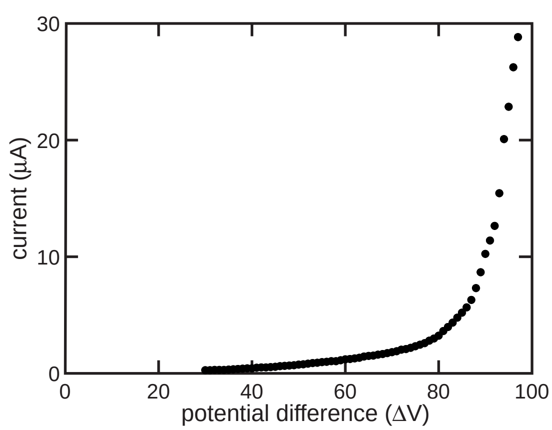

Fig. 2 Current-voltage characteristics for potential differences from 30-100 V and anode-cathode spacing of 20 μm. For potential differences above this region the use of a series resistor in the protection circuit results in ohmic behavior