MICROCAVITY VACUUM TUBE PRESSURE SENSOR

FOR ROBOT TACTILE SENSING

J. C. Jiang*
R. C. White*
P. K. Allen**

* Department of Electrical Engineering
** Department of Computer Science
Columbia University
New York, N.Y. 10027

Microstructure pressure sensors have many uses in automotive, aerospace, medical electronics and process-control industries. In addition, fabrication of tactile sensors poses a major challenge in robotics. For robotics, devices need to be small, with good spatial resolution, large pressure range, high sensitivity, and simple design for robust operation. In hazardous environments, sensor operation should be radiation and temperature insensitive. To date, many technologies have been tried. However, none have become dominant.

A new microstructure pressure sensor for robot tactile sensing is currently under development. The technology is inherently generic making it applicable in other areas mentioned above. The design is based on a silicon vacuum diode configuration, which has a cold field emission cathode and a movable diaphragm anode, as shown in Fig.1. The cathode is a sharp tip. When a positive potential difference is applied between the cathode tip and anode, an electric field is generated at the tip that allows electrons to tunnel from inside the cathode to the vacuum outside, if it exceeds about 5 x 10^7 V/cm[1]. The field at the tip, and quantity of electrons emitted or emission current, are controlled by the anode potential. The anode deflects in response to differential pressure to produce current change.

The theoretical basis of field emission is well described by the Fowler-Nordheim Equation[2]

$$J=1.54\times10^{-6}\frac{E^2}{\phi t^2(y)}\exp[-6.83\times10^{7}\frac{\phi^{3/2}}{E}f(y)]$$

Where J is the current density in amperes per square centimeter, φ is the work function of the emitter in electronvolts, E is the electric field in volts per centimeter, The functions f(y) and t(y) have been calculated to be 1, approximately.[3]

The simple expression of above equation is

$$\frac{I}{V^2}=a\exp(-\frac{b}{\beta V})$$

where a and b are constants, and E = βV, V is voltage across the cathode tip and anode, β is the local field conversion factor at the emitting surface, determined by the structure of tip and distance between tip and anode.

The field at the apex of the tip is inversely proportional the tip radius. Sharp needle structure tips are fabricated to achieve the requirement for high electric field which yield reasonable field emission current, Emission current density vs. bias voltage (Fig.2) pressure response characteristics (Fig.3), and sensitivity, for different diaphragm dimensions, have been calculated. Device modeling indicates that this structure offers high sensitivity, micrometer scale and IC compatibility. As a vacuum electronic device, it should be tolerant of high temperature and radiation. The sensor can be integrated with analog circuits on the same chip to provide a high-performance output signal. Both D.C. and A.C. operation have been considered. In D.C. mode, bias voltage influences sensitivity.

Using standard integrated-circuit fabrication techniques, we have fabricated various sealed microcavity vacuum diodes. Silicon tips have been made on <100> silicon wafer with radii of curvature of 0.02 to 0.1 micrometer, about 1.5 micrometers in high (Fig.4). We are using a new sacrificial layer technique to create the vacuum cavities. The metal diaphragms have dimensions on the order from 10x10 to 100x100 micrometers. One kind of diode structure (Fig. 5) has an array of silicon tips under a 25 x 25 x 1 cubic micrometer Aluminum diaphragm. The vacuum gap between tip and diaphragm is less than 0.5 micrometer. The vacuum sealing of our device is achieved in a 10^{-6} torr vacuum chamber. Fig.6 shows a I-V curve of a vacuum diode with a single tip. This response curve is taken with atmospheric pressure outside the diaphragm. Fig.7. is Fowler-Nordheim plot of this data. Linearity indicates that I-V characteristic follows the Fowler-Nordheim relation. Various tip and anode fabrication procedures are currently under investigation to maximize the pressure response.

The extremely small size of each sensor cell coupled with known fabrication techniques will allow us to design an array sensor using these cells that will have the advantages of redundancy and the ability to integrate tactile response over a number of sensor cells. High density and high sensitivity sensor arrays have particular advantage in delicate operations of robotic hands.

REFERENCES

[1] I. Brodie, " Physical considerations in Vacuum Microelectronics Devices, IEEE tran. Electron Devices, vol 36, p. 2641, 1989.

[2] R. H. Fowler and L. Nordheim, "Electron emission in intense electric field," Proc. Royal Soc. London, series A, Vol. 119, pp.173, July 1928.

[3] R. E. Burgess, H. Kromer, and J. M. Houston,Phys. Rev. 90, 515 (1953)

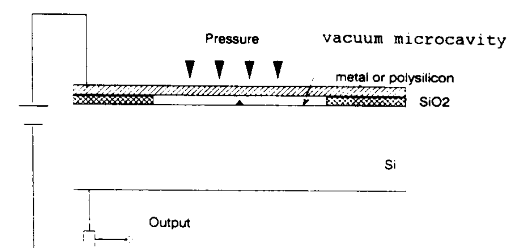

Fig. 1: A schematic vacuum diode pressure sensor.

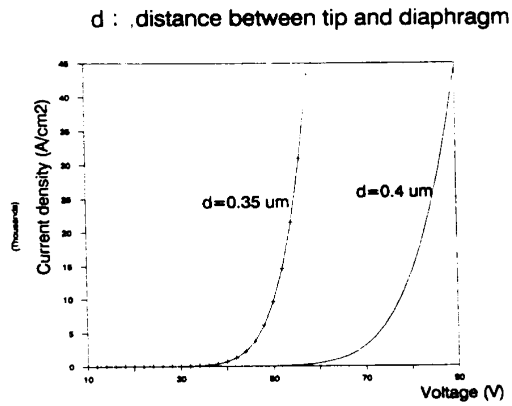

Fig. 2: Theoretical emission current density vs. bias voltage for a silicon tip with radius of 0.02 micrometer.

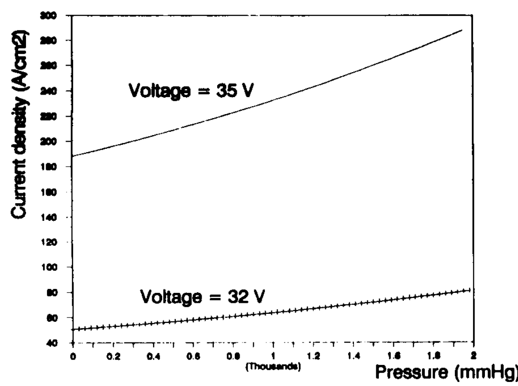

Fig. 3: Theoretical emission current density vs. pressure; diaphragm is 30 x 30 x 1 cubic micrometer, distance between tip and diaphragm at zero pressure is 0.3 micrometer.

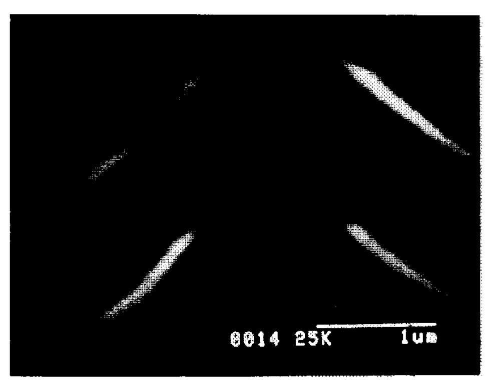

Fig. 4: A SEM micrograph showing a silicon tip.

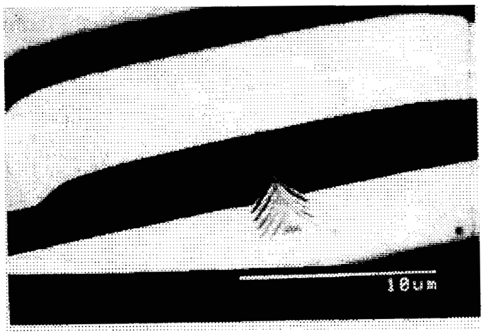

Fig. 5: A SEM micrograph showing a vacuum diode structure with a tip array under the Al diaphragm.

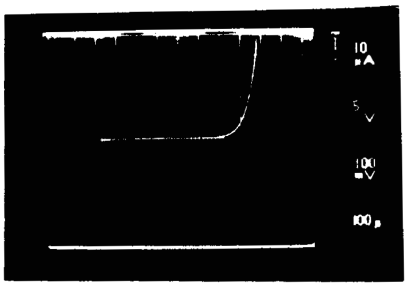

Fig. 6: I-V characteristic of a vacuum diode with a single silicon tip.

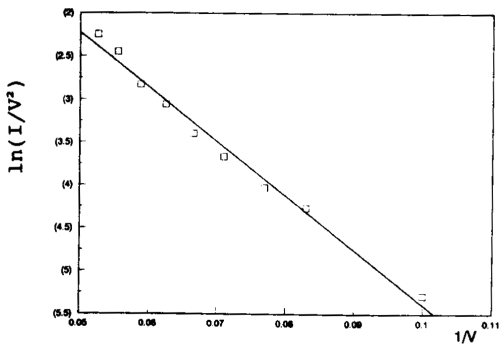

Fig. 7: Fowler-Nordheim plot of I-V curve in Fig. 6.