

## The influence of surface treatment on field emission from silicon microemitters

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

1991 J. Phys.: Condens. Matter 3 S231

(<http://iopscience.iop.org/0953-8984/3/S/036>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 129.252.86.83

The article was downloaded on 27/05/2010 at 11:24

Please note that [terms and conditions apply](#).

## The influence of surface treatment on field emission from silicon microemitters

A J Miller and R Johnston

GEC-Marconi Limited, Hirst Research Centre, East Lane, Wembley, Middlesex  
HA9 7PP, UK

Received 25 April 1991

**Abstract.** Field emission from micron-scale structures is investigated as part of a research programme on vacuum microelectronics. Chemical cleaning and ion bombardment of silicon cones is described. The influence of these treatments on the field emission energy spectra is discussed and analysed using a model of resonance-enhanced tunnelling through an adsorbate layer. It is concluded that resonant tunnelling is a mechanism of importance for explaining low energy structure in field emission energy spectra.

### 1. Introduction

Micron scale field emitting structures based on sharp tips with integral grids have been fabricated as part of a research programme in vacuum microelectronics. Surface physics and chemistry are of central importance for materials and processing choices in this project and silicon is being used as a vehicle to study the fundamental physics of the emission process, as its surface properties are comparatively well understood.

Controlling field emission from these structures requires the preparation of a tip of approximately 10 nm radius in a reproducible stable state. Chemical cleaning, ion bombardment and field desorption modify the surface of the tip and these techniques lead to changes in the field emission characterisation. The tips are characterized by measuring the total current as a function of applied voltage and also the field emission energy distribution.

### 2. Surface treatments

The structure shown in figure 1 is produced by adapting standard silicon processing techniques. The apex of the silicon emitter cone is at the centre of a circular hole in a metal grid. This structure is certainly contaminated with oxide on the silicon tip when received from processing. Immediately before introducing the sample into the vacuum system it is dipped in a 5% solution of HF for ten seconds. It has been shown [1] that this procedure removes all oxide from the surface which is left hydrogen passivated and will remain so for several hours in a dry environment.

Ion bombardment is used to remove contamination species from the field emitter, while remaining in the UHV environment. Argon ions were used from a scanning

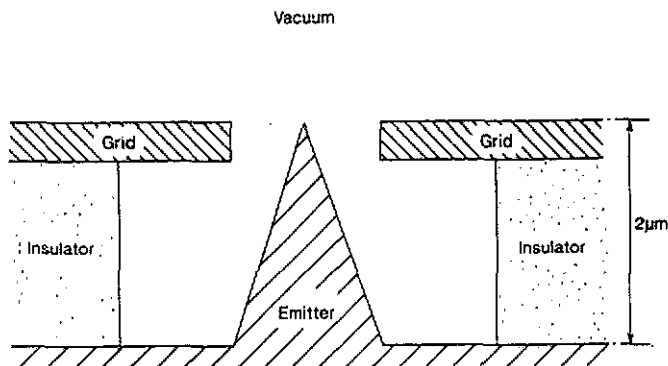


Figure 1. A sketch of a field emitter electron source. Shown is the emitting cone, the metal grid and the insulating spacer.

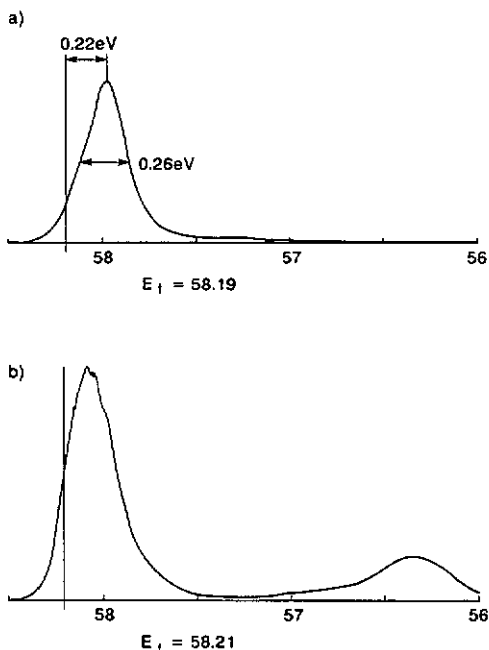
ion gun, and the energy used was 500 eV. All electrodes of the specimen were earthed during the bombardment, and the flux of ions was calibrated so that the mean number of ion impacts per  $10 \text{ \AA}^2$  surface area, considered as an area presented by one surface atom, per unit time is known.

### 3. Field emission spectroscopy

Standard arguments [2], which apply to the gridded micron sized structures considered here, show that for an emitter with constant radius of curvature, all movement of the electrons becomes radial as they leave the surface. This means that only the total energy of the electrons is conserved and not the separate components of the kinetic energy parallel and normal to the surface as would be the case for a flat emitter. Under the supplementary assumption of uniformity of emission over the area of constant curvature an energy analyser of small acceptance angle will measure the total energy distribution (TED) and so experimental results for these tips should be compared with theoretical calculations of the TED. If this assumption of uniformity can not be made due to contamination or surface roughness, for example, then the interpretation of data obtained from such an energy analyser is ambiguous and this must be considered when interpreting spectra, especially quantitative aspects such as peak widths.

Figure 2(a) shows the energy distributions obtained from a chemically cleaned array of eighty silicon tips which have undergone immersion in HF, as described above. In figure 2(b) it can be seen how this spectrum develops over one day, during which a peak has appeared at low energy and after several days the peak near the Fermi energy has vanished. This is surprising, under UHV, because in a  $10^{-10}$  mbar vacuum there is only time to form a monolayer of contamination in one day.

The spectrum in figure 2(a) can be interpreted by invoking the theory of conduction band emission formulated by Stratton [3] and supplemented by a Thomas-Fermi theory of band bending. A companion paper [4] describes a model, of field emission from silicon through an adsorbate layer into the vacuum, which provides a mechanism for the increase in current with contamination. The formulae for the total energy distribution of emission are given (equations (1) and (2) of that paper). Figure 3 shows the effective tunnelling potential and band structure for this model. An appropriate choice of parameters produces structure in the TED, which shows that a resonance in

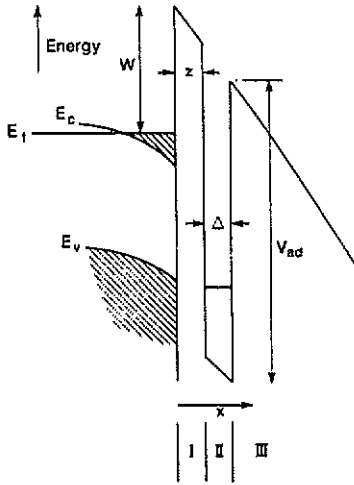


**Figure 2.** The field emission energy spectrum is shown (a) after HF cleaning then (b) after one day in UHV. Note the appearance of an emission peak at lower energy.

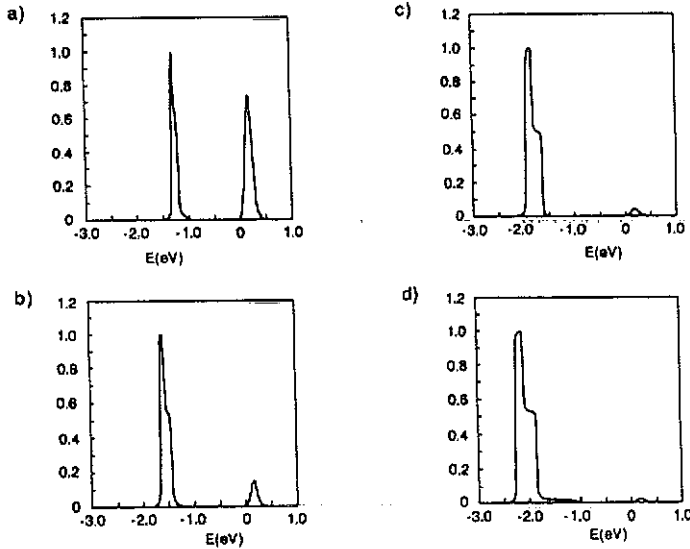
the adsorbate potential may enhance the valence band emission so that it can even come to dominate the spectrum. In figure 4 the theoretical results with resonant tunnelling from the valence band at four values of the applied field are shown. For these values of the field the emission for the case without the adsorbate potential would be dominated by electrons from the conduction band.

Figure 5 shows the result of ion beam cleaning of an array of tips. The dose of ions was approximately 10 per  $10 \text{ \AA}^2$ . The bombardment removes the peak at low energy which developed due to contamination. This is interpreted as the removal of an adsorbate layer: Calculations have shown that resonant tunnelling through such a layer can so enhance the emission that the spectra are dominated by structure several electron volts below the Fermi energy. Experimentally such structure has been observed at energies even lower than that shown in figure 5.

The movement of peaks with applied voltage provides additional information on their provenance and the associated mechanism for emission, whether it is of resonant, dissipative or Fowler-Nordheim type. Figure 6 shows how the position of the peak maximum changes with applied voltage. The position of the maximum is measured from the voltage applied to the cathode. At low voltage there is a single peak, at intermediate voltages two peaks, and at high voltages one peak; the first one having died out (figure 6(a)). More complicated behaviour is seen in figure 6(b). The Fowler-Nordheim model (free electron gas, triangular tunnelling barrier plus image potential) does not describe the data because it does not predict that peaks move as a function of field. Neither can the result be explained by simple resistive loss in the tip, since in addition to the low energy peak, there remains a distinct Fermi edge at the applied bias. Although the result can no longer be explained by the theoretical model proposed



**Figure 3.** The surface band structure together with the tunnelling barrier are shown. The potential well in region II of depth  $V_{ad}$  and width  $\Delta$  models the effect of the adsorbate layer. The electric field can be varied independently in regions I, II and III. The valence and conduction band edges are  $E_v$  and  $E_c$  respectively. The band bending induces an effective surface workfunction  $W$ .



**Figure 4.** The total energy distribution is shown for model parameters  $V_{ad} = 7.6$  eV,  $\Delta = 2$  Å,  $z = 2$  Å,  $E_F = 0.2$  eV and  $W = 4$  eV; for four values of the electric field (a)  $0.3$  eV Å $^{-1}$ , (b)  $0.4$  eV Å $^{-1}$ , (c)  $0.5$  eV Å $^{-1}$  and (d)  $0.6$  eV Å $^{-1}$ .

above with a single resonance, either two species of an adsorbate or one adsorbant with multiple resonances would provide the required spectra. That both peaks have the same dependence on field indicates that a single well with multiple resonances provides the most likely explanation.

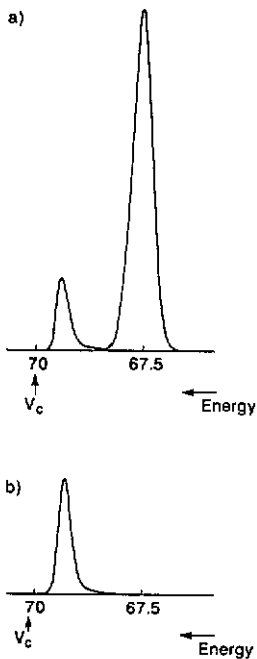


Figure 5. The field emission energy distribution is shown for a 64-tip array (a) before (b) after ion bombardment.

#### 4. Conclusion

It has been shown that micron scale field emitter tips exhibit a large variety of spectroscopic structure. It has also been shown that it is possible to control this structure, to an extent, by chemical cleaning and ion bombardment. Recontamination of the treated surface remains a problem and it has been shown (figure 2) that monolayer contamination leads to low energy structure in the field emission energy spectra. The thinness of the layer and the fact that the observed features are often very narrow make dissipative loss a very unlikely mechanism. It has been argued that resonance assisted tunnelling is a feasible explanation for peaks appearing several electron volts below the emitter Fermi energy. Field emission spectroscopy allows the quality of the emitter and the effects of tip treatment to be monitored and will become more important if controllable electron beams are to be produced from submicron sources.

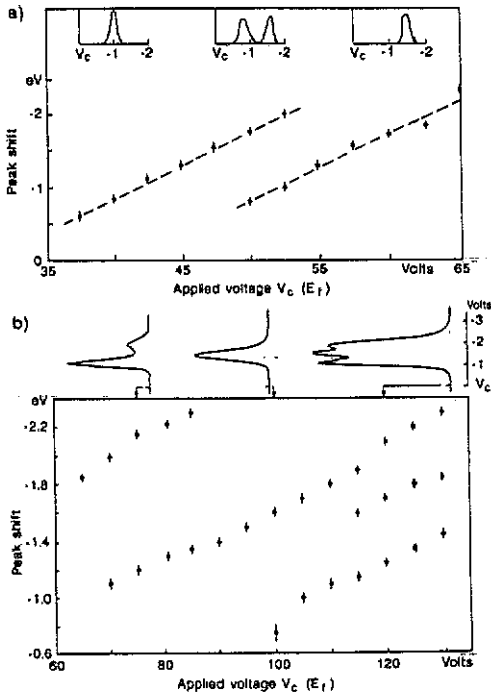


Figure 6. The shift in position of the peak in the energy distribution is shown as a function of applied voltage for two samples. The two parallel lines refer to two peaks which are followed over the voltage range in (a). A more complicated behaviour is seen with three peaks emerging in (b).

## References

- [1] Thornton J M C and Williams R H 1989 *Semicond. Sci. Technol.* **8** 47-851
- [2] Gadzuk J W and Plummer E W 1973 *Rev. Mod. Phys.* **45** 487
- [3] Stratton R 1964 *Phys. Rev.* **135** 794
- [4] Johnston R 1991 *J. Phys.: Condens. Matter* **3**