New Insights In Electron Emission From Porous Silicon Diodes

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Introduction

Porous silicon (PS) diode exhibits high-energy electron emission as illustrated in Fig. 1 (a). This device is a potential candidate for cold cathodes in future flat panel displays due to low turn-on voltage and high current stability [1-3]. As the PS layer has tree-like network of many nanometer size silicon dots [2, 3], conduction mechanism in the PS layer is also of great interest. The emission energy distribution exhibits a peak, which shifts toward higher energy with increasing positive bias applied to the Au electrode [2, 3]. This behavior is depicted in Fig.1 (b). In this work, we first quantitatively analyze the dependence of the peak energy value on the voltage applied to the Au electrode. We then study the shape of the distribution and its dependence on the applied voltage. The existing models are discussed based on the analysis.

Analysis

Figure 2 demonstrates that the peak energy (E_{peak}), as a function of the applied voltage (V_{ps}) shows linear dependence with unity slope, which we call the 'linear law' hereafter. As illustrated in Fig. 3, E_{peak} can be written as,

$$E_{peak} = eV_{ps} - W_{Au} - E_{loss}, \qquad (1)$$

where W_{Au} and E_{loss} denote the work function of Au and the energy difference between the Fermi level of the silicon substrate and the peak energy level, respectively. In general, E_{loss} is a function of V_{ps} and depends on nature of electron transport in the PS layer. The linear law, however, indicates that E_{loss} is nearly independent of V_{ps}, and is a virtually constant parameter of each individual device as shown in Fig. 4.

Figure 5 compares the energy distribution of different electron emitters. Note that the energy dispersion of the PS diode (PSD) is much larger than those of the carbon nanotube emitter (CNT) and the conventional metal tip field emitter (TIP). This indicates that the PS diodes cannot be modeled as the simple conventional field emitter arrays. The emission energy distribution of MOS emitter (MOS) has similar shape as that of PS diode. However, the PS diode and MOS emitters have different dependence on V_{ps}. Figure 6 shows the impact of V_{ps} on the energy distribution of a PS diode. Note that the increasing V_{ps} dramatically changes the distribution in the range of the smaller energy than E_{peak} (negative ΔE), while it has minimal impact in the range of the larger energy (positive ΔE). This behavior is quite different from that observed in the MOS emitters, as shown in the inset. This indicates that the simple MOS model also fails to explain the electron emission from PS diode.

Discussion

One of the existing models to address the electron emission from PS diode is the quasiballistic emission model [2, 3, 10]. This model assumes that the electron-phonon scattering is strongly suppressed in the silicon nanocrystallites in the PS layer. However, theoretical background of this assumption is still unclear, and any straightforward reason of the nearly constant E_{loss} cannot be found in this model. Another model regards the PS layer surface as the conventional field emission arrays [6]. This model, however, fails to explain the results shown in Fig. 5. In order to explain the electron emission from the PS diodes, new model has to be developed, which will be proposed in the presentation.

Summary

The peak energy plotted as a function of applied voltage obeys the linear law, indicating that E_{loss} is nearly constant of each device. Increasing V_{ps} dramatically changes the distribution in the range of smaller energy than E_{peak}, while it has minimal impact in larger energy range. Any existing model cannot explain these findings.

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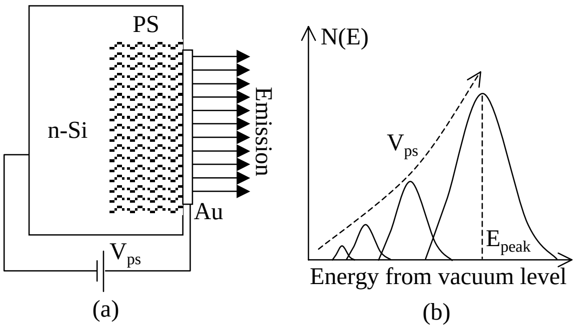

Fig. 1 (a) Schematic Illustration of the electron emission from porous silicon (PS) diode. Positive bias applied to the Au electrode (V_{ps}) injects electrons into PS layer. Electrons are accelerated in the PS layer, and some high energy electrons overcome the work function of Au, being ejected into vacuum. (b) Emission energy distribution measured from vacuum level. Peak energy Epeak moves toward higher energy with increasing V_{ps}.

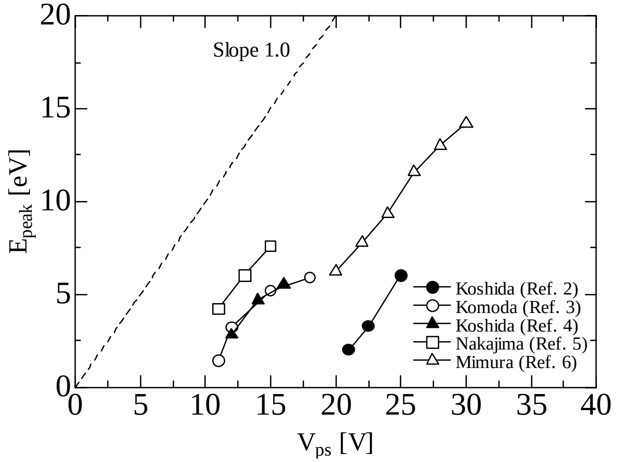

Fig. 2 Evolution of the peak energy with increasing applied voltage. Note that E_{peak} varies linearly with unity slope, which we call the ‘linear law’.

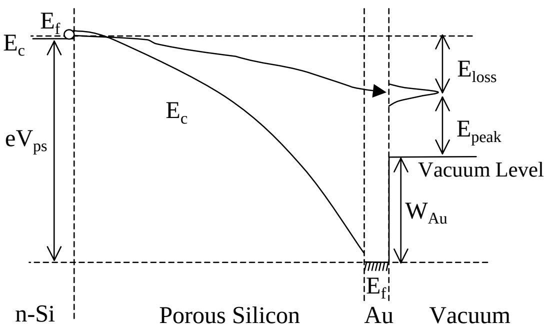

Fig. 3 Band Diagram under positive bias V_{ps}. Oxide layers in PS are not shown for simplicity [2]. The peak energy level E_{peak} can be written as $E_{peak} = eV_{ps} - W_{Au} - E_{loss}$, where W_{Au} and E_{loss} denote the work function of Au and the energy difference between the Fermi level of the n-type silicon substrate and the peak energy level, respectively .

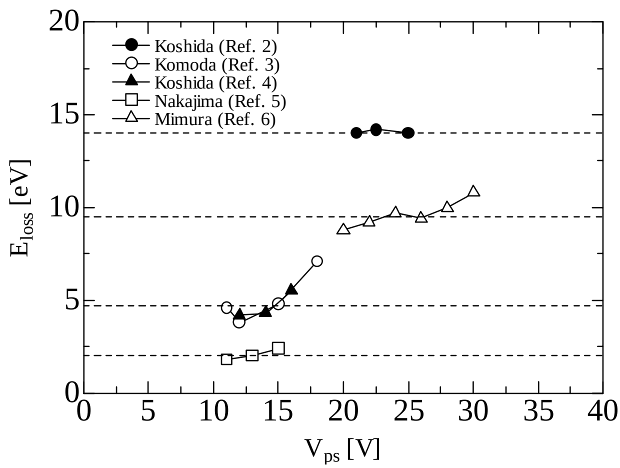

Fig. 4 Values of E_{loss} extracted from data in Fig. 2 using the relation shown in Fig. 3. Note that E_{loss} is nearly constant for each device.

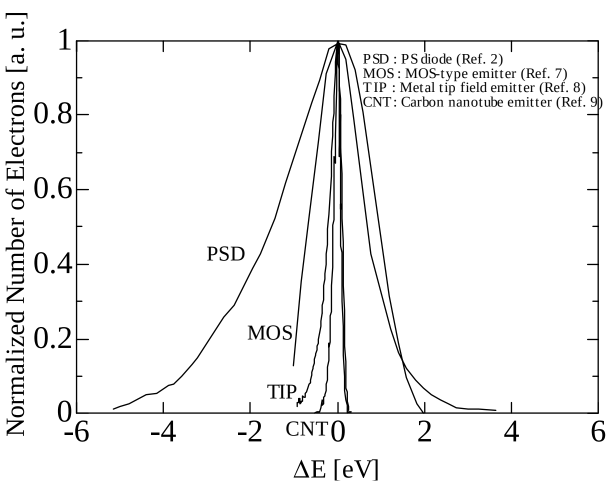

Fig. 5 Comparison of energy distributions among various electron emitters. The horizontal axis is the energy measured from the peak energy (ΔE), and the vertical axis is normalized so that the number of electrons at the peak equals unity.

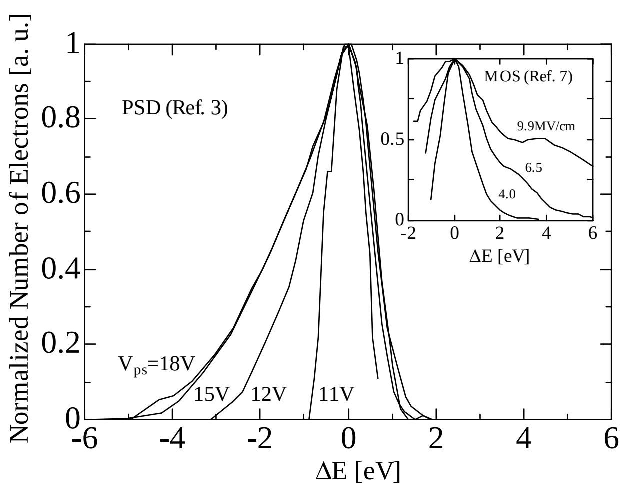

Fig. 6 Impact of increasing V_{ps} on the emission energy distribution of PS diode. The inset is the same plot of MOS emitters.