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〈연구논문〉

Stabilization of Field Emission Current

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Field Emission 전류의 안정화

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Abstract — The flicker noise in tungsten field emitters is described. The step/spike noise in carbon field emitters is compared with that made of tungsten. Disperser-type field emitters and new type of field emitters such as arrayed field emitter are explained.

요 약 — 텅스텐으로 만들어진 field emitter와 탄소로 만들어진 field emitter에서 생기는 step이나 spike 형태의 잡음에 대하여 비교 연구하였다. 그리고 dispenser 형태의 field emitter와 array 형태의 field emitter와 같은 새로운 형태의 field emitter를 설명하였다.

1. Introduction

A key problem with field emission electron emitters is stabilizing the field emission current. This instability is considered to be caused by either fluctuation in the local work function or by a change in the local geometry of the electron emitting surface. The former, called flicker noise, is a result of atom migration on the emitter surface, which induces a change in the local work function on an atomic scale. The latter is, very often, due to ion bombardment of the emitter surface, which creates a change in local geometry.

To reduce current instability, and hence to stabilize the field emission current, we need to learn more about the nature of the instability. Then using the obtained knowledge, new techniques to reduce the instability can be devised.

This paper discusses flicker noise in tungsten field emitters and step/spike noise in carbon field emitters. It also briefly comment on dispenser-type field emitters and on new field emitters, such as an arrayed field emitter.

2. Field Emission from a Metal Surface

Field emission current is a collection of electrons that tunnel through a potential barrier, a work function barrier, into a vacuum. This is done by applying an extremly high electric field to an electron emitter to reduce the barrier thickness. The field emission current density, J is expressed by Fowler-Nordheim's equation,

$$J=aF^2/\Phi\cdot\exp(-b\Phi^{3/2}/F) \tag{1}$$

where F is the applied electric field, Φ the work function, and a and b the constants.

According to Eq. (1), current instability occurs when Φ and/or F changes over time. The F will change when the local curvature of the surface changes for a constant applied potential. The change in the field emission current, ΔI, for a small change

in work function at a constant field strength F is expressed as follows by differentiating Eq. (1):

$$\Delta I = 3/2 \cdot b \cdot \Phi^{1/2} I \cdot \Delta\Phi / F \quad (2)$$

The two-site model, one current theory, deals with the change in local work function caused by adsorbed atoms hopping between two adsorption sites with different adsorption energies[1]. The model predicts, for an intermediate frequency range, that the power spectrum density (PSD) of the current fluctuation is proportional to the product of $(\Delta I)^2$, the transition rate (hopping rate) K, and a frequency dependent term

$$W(f) \sim (\Delta I)^2 \cdot K \cdot f - (2-x) \quad (3)$$

where $x = \lambda/\pi l$, λ is a trapping cross section in two dimensions (cross-diameter), and l is the distance between the sites having different adsorption energies.

Fig. 1 shows the measured PSD of the current fluctuation which is field emitted locally from the (310) face of a tungsten single crystal surface (a) and the corresponding time variation of the total field emission (TFE) current (b)[2]. Prior to all measurements, that is, before applying a high field to the emitter, the field emitter surface was flash cleaned at high temperatures. The PSD was then measured at each point for 30 seconds using a fast Fourier transform analyzer.

Our data reveals two fundamental aspects about the nature of the field emission current fluctuation. One is that the PSD shows 1/f type behavior, flicker noise, the slope of which varies from -1 at the early stage of field emission to -1.5 at the later stages. The other is that the amplitude of the PSD reaches maximum near the inflection point ((3) and (4)) of the TFE current time variation (b).

The change in slope, according to Eq. (2), arises from a change in the trapping cross section of adsorbed atoms. This could happen when the adsorption sites intially occupied by the dominant residual gas component in a vacuum, hydrogen, are taken over by carbon mono-oxide molecules, which have a much higher adsorption energy, but a lower partial pressure in a vacuum than that does hydrogen.

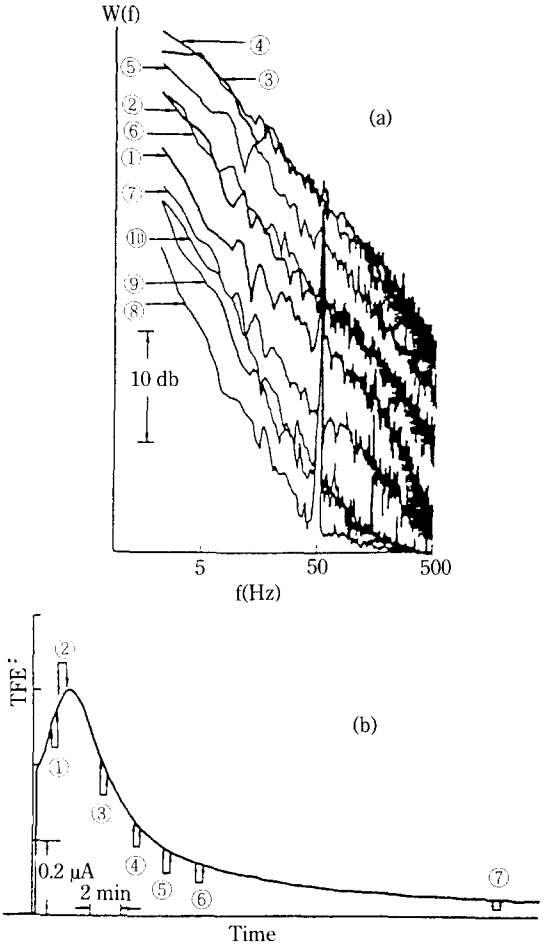

Fig. 1. PSD detecton of the field emission current fluctuation from the (310) face tungsten single crystal tip. (a) Corresponding time variation of the total field emission current. (b) time dependence of the total field emission current after flash cleaning.

Again, according to Eq. (2), the PSD amplitude strongly depends on the transition rate K. This rate in turn strongly depends on the surface coverage of the adsorbed atoms. It also depends on the energy and number density differences between hopping adsorption sites. The rate hits a maximum at the surface coverage at which adsorbed atoms are most mobile[1]. The data shown in Fig. 2 indicates that at (1) and (2), the surface coverage is so low that the transition rate is minimum. The transition rate reaches maximum near (3) and (4), where the

surface is partially covered with adsorbed atoms. The surface, then reaches full coverage near (5) and (6), where the mobility of adsorbed atoms is limited and, hence, the transition rate becomes small. Adsorption sites occupied by hydrogen may have been taken over by carbon mono-oxide at time (7) and later after (8), (9) and (10) the slope of PSD vs. f becomes steeper.

3. Field Emission from a Carbon Surface

Carbon surfaces are much more resistive against gas adsorption than metal surfaces and seem ideal as field emission electron sources. Field emission is indeed stable at a low current density and under an ultra high vacuum condition. It becomes unstable, however, at high current density, especially when operated under relatively poor vacuum conditions. This is shown in Fig. 2, where the total field emission current (TFE) from a glassy carbon surface is plotted agaist time[3]. The current fluctuation shows the step and spike noise, instead of the flicker noise normally observed for metal field emitters. When the number of steps and spikes in 20 minutes is plotted agaist the product of the field emission current and the operation pressure, a straight line can be drawn as shown in Fig. 3.

As this product is proportional to the number of ions produced during field emission, the current fluctuation we are observing has a close relation to the ion bombardment by ions produced during operation. The calculated number of CO and H ions impinging on the field emitter surface is indicated by a solid bar in the figure, which is two orders magnitude greater than measured as shown in a dotted bar. It is still believed, however, that the

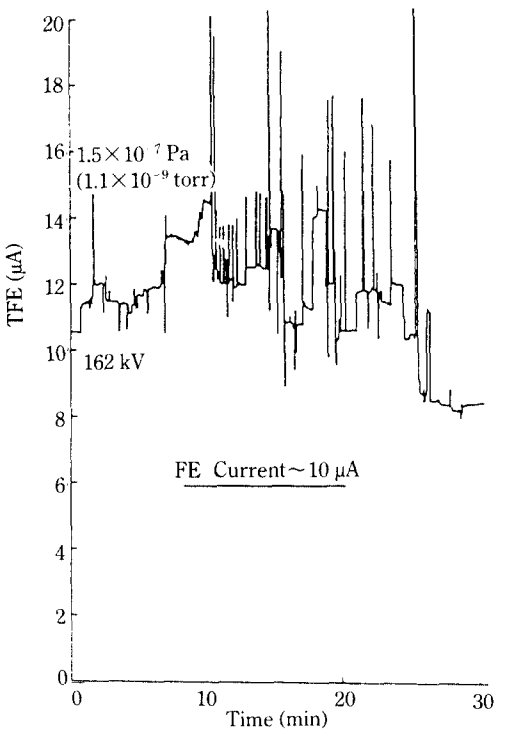

Fig. 2. Total emission current from a glassy carbon tip with a high current density.

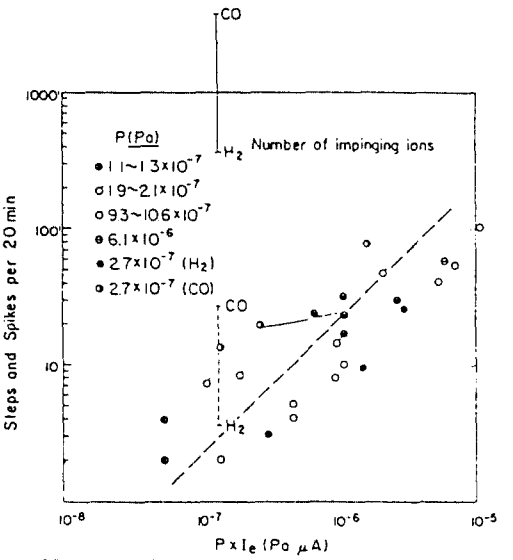

Fig. 3. Number of step and spike noises per every 20 min. vs. the field emission current times the operational pressure.

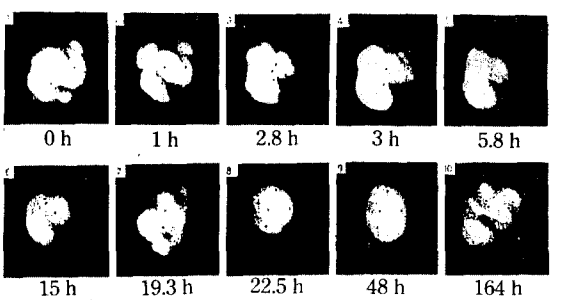

Fig. 4. Observed FEM images of a carbon field emitter as a function of time.

current fluctuation of a carbon emitter is due to the ion bombardment because as shown in Fig. 4 [4], an irreversible deformation of the emitter surface has been observed in FEM during operation.

4. Stabilization of Field Emission Current

Field emission current can be stabilized in many ways. Some typical ways are described below, all of which are based on the current fluctuation analysis.

4.1. Reduction of the Work Function Change

One method to stabilize current fluctuation is to reduce the work function change. This is clear from Eq. (2). This method works by choosing materials whose work function changes little under gas adsorption and/or intentionally using gas adsorption to create a small change in the work function. The crystal orientation with a large work function is often chosen because the change in work function is relatively small for such high work function surfaces.

4.2. Reduction of Transition Rate

There are many ways to reduce the transition rate. As the transition rate is function of adsorbate coverage θ on the emitter surface, θ must be controlled, either to an extremely high θ or to an extremely low θ. Coverage θ is expressed as a product of the gas impinging rate ν, sticking probability S, and the surface residence time of the adsorbed atoms τ as

$$\theta = S\tau\nu, \tag{4}$$

Operatiing under a good vacuum reduces ν, while the operatiing at elevated temperatures shortens the residence time ν. The sticking probability S can be reduced by using such materials as carbon and semiconductors.

4.3. Reduction of Ion Bombardment

The total number of ions produced can also be reduced by operating under a good vacuum. Surface damage due to ion bombardment can be further reduced by either using ion bombardment resistive materials or by using dispenser-type field emitters, such as a zirconiated tungsten field emitter which can heal ion bombardment damage. Another way of reducing ion bombardment damage is with better electrode arrangement based on ion trajectory calculations.

5. Summary

Some examples were presented to explain the nature of field emission current fluctuations. To stabilize such current fluctuations requires the work function change, the transition rate, or the ion bombardment. Another method, which is quite unique but not shown here, is to statistically average the fluctuations, which can be done by applying a field emission array structure.

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