Fluctuations of Field Emission Currents under Extreme High Vacuum *

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I. INTRODUCTION

The field emission (FE) electron source has been the driving force of the race for the better resolution in high-resolution electron microscopy (HREM) due to its inherent high coherency [1]. The fluctuation of FE current has been the subject of wide interests because stability of FE current is a prerequisite for HREM. For FE sources widely in use, the fluctuation has been known to be strongly affected by the operation pressure [2].

Adsorbed gas molecules on the surface of field emitters cause fluctuation of FE current through various surface kinetics; diffusion, desorption, etc. The gas molecules originate mainly from the residual gas in the vacuum chamber. Thus the decrease of pressure reduces the adsorption rate of residual gases on the emitter surface and the amount of ion bombardment, leading to stable FE. Stable FE demands thoroughly degassing of the parts around the FE source, especially the extractor electrode, because large amount of gas molecules are desorbed from the parts irradiated by e-beam. Significant ratio of the desorbed gas readsores on the surface of FE source, inducing the fluctuation of FE current.

Fluctuation of FE current depends greatly on the species of adsorbed gas. Yamamoto et al. showed that adsorption of hydrogen induces smaller fluctuation than that of carbon monoxide [3-5]. H₂ and CO are the two major components of residual gas under ultrahigh vacuum (UHV). Rather high fluctuation level of ~ 2 % for hydrogen adsorption and base pressure of 1 × 10⁻⁹ Pa of Yamamoto et al. [3], thus, indicate that adsorption of gases other than hydrogen might affect the fluctuation. To clarify the relationship between the adsorption of gases of various species and the FE current fluctuation, we first focused on the improvement of degassing and vacuum.

Here we present very stable damping behaviors of FE current in a low temperature field emission microscope (FEM), which was developed for studying the stability and fluctuation of FE current from FE sources. The FE current fluctuation had been so small to be comparable to or smaller than the resolution of a high-end commercial current meter until the tip was covered with large amount of hydrogen. The results of the shot noise measurement of FE current from W(111) tips are given.

II. EXPERIMENTAL

The XHV FEM system constructed in the present work is presented in Fig. 1. All the metal parts inside the vacuum chamber and the inner wall of the vacuum chamber were mirror-polished by electrochemical buffing, and were pre-baked in a vacuum furnace; chambers and electrical feedthroughs at 350°C, FEM components at 450°C.

Figure 2 shows the first pumping curve of the XHV system. The pressure was measured using an extractor gauge (Leybold Inc. IM540). After bakeout at 170°C for 48 hour, we activated the NEG at 450°C for 30 minmetes, following the manual instructions. The pressure reached only ~ 1 × 10⁻⁸ Pa.

Exposed to the atmosphere, NEG absorbs large amount of hydrogen gas that diffuses into the material. Exposed to a vacuum, the absorbed hydrogen gas diffuses back into the vacuum. A few times of exposure to the atmo-
The FE current was measured using a current meter (Advantest Inc., R8340A) with sampling time of 0.5 second. The integration time of the analog-to-digital converter in the current meter was set to 0.2 second, which corresponds to low-pass filtering with cutoff frequency of \( \frac{1}{2 \pi f_c} \)

III. STABLE FE FROM W(111) TIPS UNDER XHV

After flash heating of a FE tip under ultra-high vacuum (UHV), FE current usually decreases rapidly due to the adsorption of residual gas molecules on the clean surface— the decreasing part of the FE current vs. time curve was called “the ever decreasing region” [3]. FE current slows its decreasing speed with time to reach finally the non-decreasing region, indicating the saturation of the initially clean surface.

The FE current was measured using a current meter (Advantest Inc., R8340A) with sampling time of 0.5 second. The integration time of the analog-to-digital converter in the current meter was set to 0.2 second, which corresponds to low-pass filtering with cutoff frequency of \( \frac{1}{2 \pi f_c} \). The integration time of the analog-to-digital converter in the current meter was set to 0.2 second, which corresponds to low-pass filtering with cutoff frequency of \( \frac{1}{2 \pi f_c} \).
The noise of FE currents ranging from 10 pA to 100 μA was measured using the XHV-FEM. FE-tips were electrically connected to a high-voltage BNC feed through of the floating shield by a semi-rigid coaxial cable. The background noise was measured to be smaller than $1 \times 10^{-14}$ A. Current fluctuations of FE were preamplified in a wide bandwidth preamplifier, and the spectral intensity of the fluctuation of FE currents was measured by a spectrum analyzer (Agilent Inc. 4396B).

Results of noise measurements at 4 Hz and 9 Hz are given in Fig. 7. The power spectral data follow the theoretical shot noise line, $2eI$, quite well up to $I = 1$ nA, with a linear dependence on dc current, but showed non-linear dependence for FE currents of 1-100 nA. The power spectral intensity data followed the shot noise line better at 9 Hz, and this was the new record of the lowest frequency shot noise measurement.

The spectral intensity depends on the average DC current with the relation, $S(I_D) = C \cdot (I_D)^{\alpha}$, where $I_D$ is the DC current level, $C$ is a constant, and $\alpha$ is an exponent of the power law [7]. This relation gives information on the driving mechanism of the fluctuation. $S(I_D)$ depends linearly on $I_D$ with $\alpha = 1$ for the shot noise. For flicker noises, $S(I_D)$ usually shows a quadratic current dependence with $\alpha = 2$, but non-integer values of $\alpha$ also often show up.

The noise measurement at 4 Hz yielded $\alpha \approx 1$ for currents ranging from 10 pA to 1 nA, and $\alpha = 1.4$ for FE currents of 1-100 nA. This non-integer power-law dependence on current might suggest a different type of noise. The noise measurement at 9 Hz yielded $\alpha \approx 1$ for currents ranging from 10 pA to 100 nA, and non-integer value of $\alpha$ was not observed. For currents larger than 100 nA, the noise measurement gave $\alpha \approx 2$ at both frequencies, indicating that the flicker noise dominated at large currents.

At frequencies higher than 1 kHz, the shot noise can be measured with currents ranging from 30 nA to 30 μA. Currents larger than 30 μA presented flicker noise of $\alpha \approx 2$. The noise measurement could be stably performed even at 200 μA, although it was governed, within the bandwidth of the noise measurement system, by the flicker noise.
V. SUMMARY

In summary, the noise of FE currents was measured under XHV for elucidating the electron emission mechanism of nano FE sources. An extreme high vacuum field emission microscope (XHV-FEM) was constructed for the study of inherent fluctuations of field emission current. The damping and fluctuation behaviors of FE current from clean W(111) tips at 90 K were observed using the XHV-FEM. The fluctuation of a field emission (FE) current for a clean W(111) tip was so small to be comparable to the corresponding shot noise fluctuation. The noise of field emission currents ranging from 10 pA to 100 µA was measured under $\sim 7 \times 10^{-10}$ Pa. The lowest frequency measurement of shot noise was recorded at below 10 Hz.