Extremely Stable and Harsh-Environment Devices by Transfer Mold Field Emitter Fabrication Method

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Extremely stable and harsh-environment devices have been fabricated by Transfer Mold emitter fabrication method and by using amorphous carbon (a-C) as an emitter material to realize the vacuum nanoelectronic devices such as electric propulsion engines, power switching devices and field emission displays (FEDs) in harsh environments, for example, in strong radial atmospheres, in high and low temperature atmospheres, and in oxidation gas atmospheres during FEDs fabrication process.

Transfer Mold a-C field emitter arrays (FEAs) have the base length of 110 nm, which is one of the smallest emitter size ever reported. The 2.9 nm emitter tip is also one of the sharpest tip radii among various kinds of FEAs. These tip radii are similar to the diameters of the single-walled CNTs, 0.4–3 nm, or less than the diameters of the multi-walled CNTs, 5–10 nm.

Moreover, they exhibited the most stable field emission characteristics having the emission fluctuation ratio of ±1.6%, which is one of the lowest value ever reported.

The field emission characteristics of conventional FEAs should be degraded under the harsh environments. Therefore, FEAs must need low work function and environment-hard emitter materials in harsh environments.

The Transfer Mold emitter fabrication method has been developed to obtain sharp, uniform, low operation voltage FEAs using various materials including low work function materials. By using this method, the extremely sharp FEAs can be obtained reproducibly and uniformly [1]. Moreover, the extreme sharp tip can realize the enhanced reliability of FEAs by using the size reduction method of emitter base length.

Figure 1 shows the Transfer Mold FEA fabrication process [1]. Si mold substrates were formed by anisotropic etching in Fig. 1(a). Thermal SiO₂ layer was formed in the Si mold to allow intrinsic tip sharpening of the FEAs in Fig. 1(b). The a-C thin film as the emitter material was deposited inside the Si mold by plasma enhanced chemical vapor deposition in Fig. 1(c). Nickel was filled by the sputtering method in Fig. 1(d), and bonded onto the glass substrate by anodic bonding. The Transfer Mold a-C FEAs were obtained after the removal of the Si mold substrate in Fig. 1(e). Transfer Mold FEAs were fabricated by the control of mold size using the e-beam lithography. The field emission characteristics were evaluated at the short distance of 10 µm between anode and cathode.

Figure 2 shows SEM images of Transfer Mold a-C FEAs having base lengths of (a) 1570 nm, (b) 380 nm, (c) 190 nm and (d) 110 nm, respectively. The average tip radii of Transfer Mold FEAs with the base lengths from 1570 nm, 380 nm and 190 nm to 110 nm exhibited the decrease from 7.8±1.5 nm, 3.8±1.3 nm and 3.3±1.0 nm to 2.9±0.8 nm, respectively. The average emitter tip radii and those standard deviations almost decrease as the emitter base lengths decrease.

Figure 3 shows the I-V characteristics of Transfer Mold FEAs as a function of emitter base length. Turn-on fields decreased from 17.5 V/µm to 11.9 V/µm as the base length of FEAs decreased from 1570 nm to 110 nm, because the geometric factors almost increase. The turn-on fields of Transfer Mold a-C FEAs, 11.9–17.5 V/µm are lower than those of other conventional FEAs such as CNTs FEAs, Spindt-type FEAs and Gray-type FEAs having the approximated turn-on fields of 50–600 V/µm [2]. Transfer Mold a-C FEAs can be applicable for reliable vacuum nanoelectronic devices.

The Transfer Mold a-C FEAs having the base length of (a) 110 nm, (b) 190 nm, (c) 380 nm and (d) 1570 nm, exhibited the stable emission fluctuation ratio of ±1.6%, ±1.7%, ±1.7%, and ±1.7%, respectively, without a resistive layer due to the extremely uniform geometric factors as shown in Fig. 4. These values are one of the lowest values ever reported. However, the emission fluctuations of the conventional FEAs with and without resistive layers are 5–100% and more than 100%, respectively. Moreover, even under the in-situ oxygen radical treatments, the Transfer Mold a-C FEAs without the resistive layer have the emission fluctuations of as low as ±4.5–4.8% compared with those of conventional FEAs with and without resistive layers, 5–100% and more than 100%, respectively. Therefore, the extremely sharp, uniform, stable and environment-hard Transfer Mold a-C FEAs is useful for the stable and reliable harsh-environment devices to a great extent.

In addition, pixel type field-emission electric propulsion (FEEP) and pixel type ion engine using Transfer Mold FEAs are proposed in Fig. 5(a) and (b), respectively. The ion emitter arrays and electron emitter arrays, whose electrons can neutralize positively charged particles, can be fabricated on the same panel. These pixel type electric thrusters give the easiness of getting large and small size thruster.

Extremely stable Transfer Mold a-C FEAs is useful for the reliable vacuum nanoelectronic devices such as electric propulsion engines, power switching devices and FEDs in harsh environments to a great extent.

Figure 1 Fabrication process of Transfer Mold FEAs.

(a) Si anisotropic etching
(b) Tip sharpening by thermal oxidation
(c) Deposition of a-C film inside Si Mold by PECVD
(d) Filling Ni by sputtering
(e) Etching Si Mold and SiO₂ layer

Figure 2 SEM images of Transfer Mold a-C FEAs having emitter base length of (a) 1570 nm, (b) 380 nm, (c) 190 nm and (d) 110 nm.

Figure 3 I-V characteristics of Transfer Mold a-C FEAs as a function of emitter base length.

Figure 4 Emission fluctuations of Transfer Mold a-C FEAs having emitter base lengths of (a) 110 nm, (b) 190 nm, (c) 380 nm and (d) 1570 nm with or without radical treatment.

Figure 5 (a) Pixel type field-emission electric propulsion (FEEP) using Transfer Mold FEAs and (b) Pixel type ion engine using Transfer Mold FEAs.