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Performance Investigation of Field-Emission Device Surrounded by High-k Dielectric (FESH)

Kensuke Murashima and Yasuhisa Omura
Graduate School of Eng, Kansai University, 3-3-35, Yamate-cho, Suita, Osaka 564-8680, Japan
Phone: +81-6-6368-1121 E-mail: gd4m726@ipcku.kansai-u.ac.jp

1. Introduction

Field-emission device (FED) arrays attract extensive attention from a viewpoint of low-power display [1] and low-noise devices [2]; recently, device structures and materials, e.g. carbon nanotube and diamond [3], are studied to increase field emission current density.

In this paper, we propose Field-Emission device Surrounded by High-k dielectric (FESH) with the Spindt-type emitter [4]. We discuss fundamental characteristics of the FESH using the 2-D device simulator (Synopsis DESSIS) [5]; dc and ac characteristics are investigated in detail. In addition, dynamic operation of FESH is evaluated by applying a large signal to.

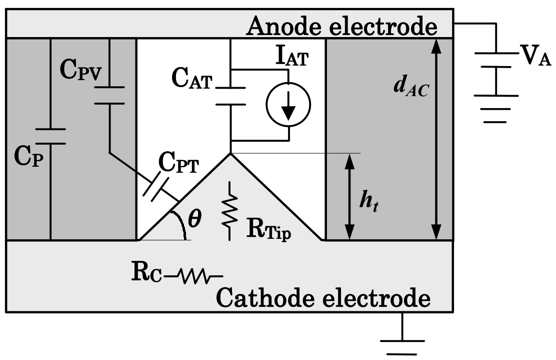

Fig. 1: Schematic structure of FESH.

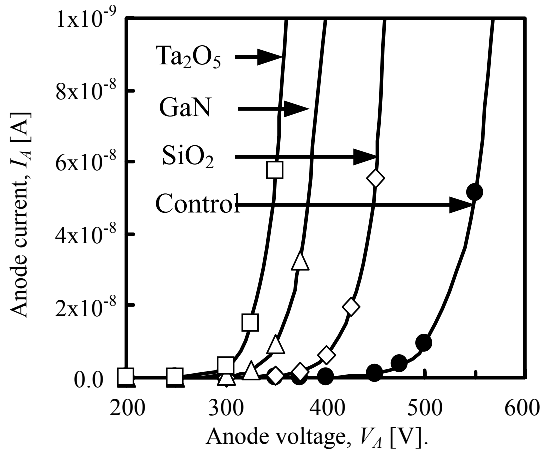

Fig. 2: I_A-V_A characteristics for dc bias

2. Device structures

FESH is shown in Fig. 1; an important aspect is a high-k dielectric surrounding the emitter. It is assumed that anode and cathode electrodes including emitter tip are n^+-Si with the doping level of 1.0×10^{20} cm^{-3}; the anode-to-cathode distance (d_{AC}) is 1.35 μm and the tip height (t_h) is 98 nm (the tip angle θ is $\tan^{-1} 2$ and the 2-nm wide top of tip is flat). FESH is 1 μm wide and 0.2 μm long. We assume three kinds of dielectric; relative dielectric constants (ε_r) are 3.9 (SiO_2), 9.5(GaN), or 25.0(Ta_2O_5).

3. Results and Discussions

Fig. 2 shows the anode current (I_A) vs. anode voltage (V_A) characteristics with or without high-k dielectric. It is conspicuously seen that the threshold voltage (V_{th}) drops by inserting a high-k dielectric; V_{th} decreases with increase in susceptibility (ε_r) of dielectric. When V_{th} is defined as V_A where I_A is equal to 10 pA, we have 37 % drop of V_{th} by inserting Ta_2O_5. By surrounding the emitter with high-k material, FED has additional parasitic capacitances (C_P, C_{PT} and C_{PV}) in the system. When the high-k dielectric is inserted around the emitter, the electric field of vacuum space near the tip relatively increases because of $C_{PT}<C_{PV}$. This results in enhancement of the electric field near the emitter tip and the increase in emission current; subsequently, V_{th} drops significantly as shown in Fig. 2.

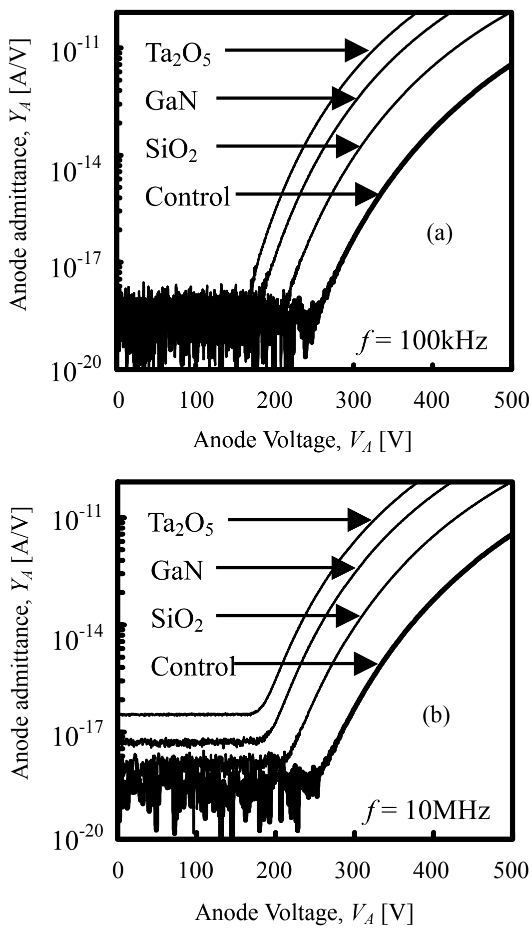

Fig. 3: V_A-Y_A characteristics

Fig. 3 shows anode admittance (Y_A ($=dI_A/dV_A$)) dependencies on V_A for a small signal with the frequency (f) of 100 kHz and 10 MHz. When f is 100 kHz (see Fig. 3(a)), the simulated Y_A values are almost the same in a low anode voltage range (off region). This suggests that the high-k dielectric does not bring out a significant influence except for threshold lowering. When f is 10MHz (see Fig. 3(b)), Y_A increases in a low V_A range; this suggests that the high-k dielectric surrounding the emitter reduced the admittance between the anode and the cathode. So, a higher ε_r leads to a larger Y_A in a low V_A range.

Fig.4 shows the anode admittance (Y_A') at a low V_A as a function of f for various high-k materials. It should be noted that Y_A' rapidly increases for f>10 MHz. This is a serious problem because of a stand-by ac-power loss. So, we define the threshold admittance Y_{th} at $V_A= V_{th}$; we can extract the cut-off frequency (f_T) at which Y_A exceeds Y_{th}. Extracted f_T is shown in Fig. 5; we can expect giga-Hz operation even for $\varepsilon_r = 25$.

In use of FESH, we must assume more strict condition of operation. Fig. 6 shows transient-response characteristics for two different anode pulses. Simulation results of I_A for rectangular pulse (V_{AR}) applied to the anode are shown in Fig. 6(a) for various high-k materials. The rectangular pulse has the rise (fall) time of 0.025 ms and the pulse width of 0.45 ms, and its plateau is V_{th} so that the maximal I_A value is identical to each other (~1.0×10^{-11} A). We can see that a large I_A transiently flows at the rise (fall) of V_A when the rectangular pulse is applied to. The transient current increases with ε_r value, which strongly indicates that the high-k material surrounding the emitter gives a great transient current. Such a transient current is undesirable to FED because of suppression of device fatigue. So, we tried to apply a half-sinusoidal anode voltage (V_{AS}) to the anode of FESH (see Fig. 6(b)). Fundamental parameters of half-sinusoidal pulse are identical to the case of rectangular pulse. I_A has two components; one is the electron field emission current appearing at around 0.35 ms; the maximal emission current level is almost identical to that of the rectangular pulse. The other is the ac leakage current through the high-k dielectric; the admittance of a dielectric is given by ωC_h, where C_h is the effective capacitance of high-k dielectric. Higher ε_r value results in a larger ac leakage current as expected. Since a higher pulse frequency yields a larger ac leakage current, the electron emission current is behind the leakage current. So, an optimal ε_r value should be chosen in FESH design. Thus we conclude that the sinusoidal anode voltage should be used to extract a desirable performance from FESH.

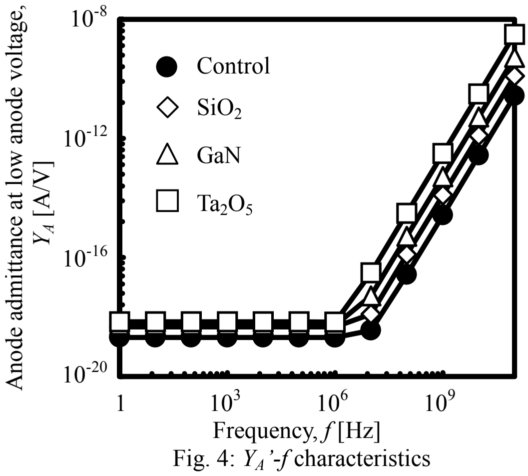

Fig. 4: Y_A'-f characteristics

References

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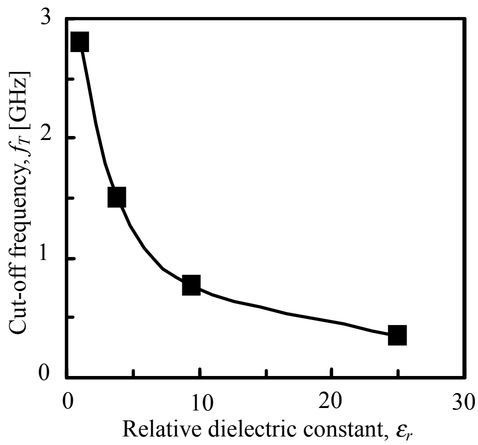

Fig. 5: ε_r-f_T characteristics

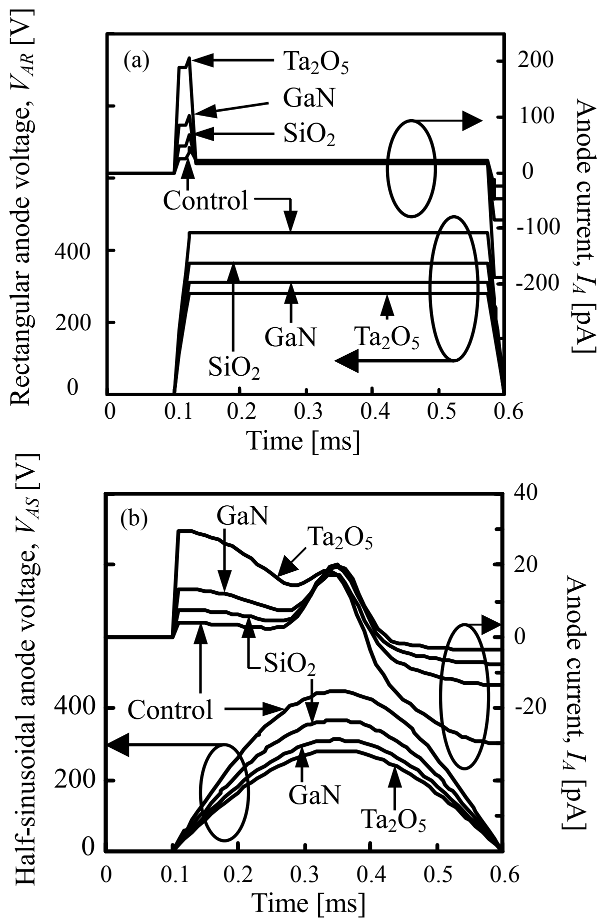

Fig. 6: Transient response for two different anode pulses