Journal of the Korean Vacuum Society
Vol. 2, No. 3, September 1993, pp. 331-334

<연구논문>

Fabrication and Applications of Comb-Shaped Lateral Field Emitter Arrays

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(Received July 9, 1993)

빗살무늬의 수평형 고압전자 방출장치의 구성과 응용

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(1993년 7월 9일 접수)

Abstract — Various FEAs with lateral and vertical structures have been investigated. Lateral FEA has a coplanar configuration of the emitter and the gate is more suitable for high frequency device application. The structure and emission characteristics and applications of a comb-shaped lateral FEA are explained.

요 약 — 여러 종류의 수직 또는 수평 형태의 field emitter array가 연구되었다. 그 중 수평형의 FEA는 emitter가 동일 평면 위에 구성되어 있고, gate는 고주파의 응용을 위하여서는 더욱 적합하다. 이 빗살 모양의 FEA의 구조, emission 성질, 응용에 대하여 설명한다.

1. Introduction

Vacuum microelectronics has the great potential for generating high-performance microdevices such as ultrafast and radiation-resistant devices, flat-panel displays, sensors and so on[1]. For realization of the potential, however, it is essentially important to develop cold cathodes with emission stability and life time enough for putting them in practical use. Field emitter array (FEA) fabricated with advanced microfabrication technology is a most promising candidate for the cold cathode.

Various FEAs with lateral and vertical structures have been investigated so far[2]. Lateral FEA has a coplanar configuration of the emitter and the gate and is more suitable for high frequency device application because of its small emitter-to-gate capacitance compared to vertical FEAs. In this paper, structure, emission characteristics and applications of comb-shaped lateral FEA which has been originally developed by the author's group[3, 4].

2. Comb-Shaped Lateral FEA

Fig. 1 shows a schematic diagram of the comb-shaped FEA. The present FEA consists of an array of emitter tips and gate electrode and has structural parameters such as the edge width (w), pitch (p), emitter-to-gate spacing (g) and emitter thickness (t). The emission characteristics strongly depend on the above parameters, especially on the p/w ratio. The optimal value of the p/w ratio is about 3[3, 4].

Fig. 2 shows a SEM micrograph of the comb-shaped FEA fabricated by a self-aligned and two-step etching process described in ref. 4. The emitter has 150 tips and is made of 0.2 μm-thick tungsten (W) film deposited on a quartz substrate. The edge width and the pitach are $w=3$ μm and $p=10$ μm, respectively: $p/w=3.3$. The gate electrode is 0.5

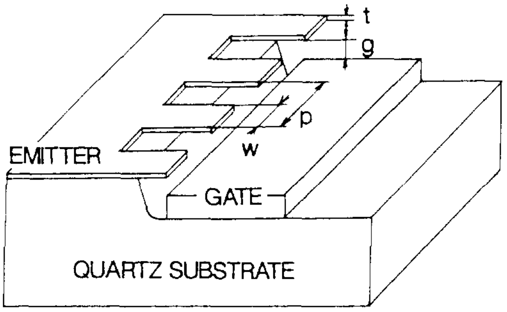

Fig. 1. Schematic diagram of comb-shaped lateral FEA.

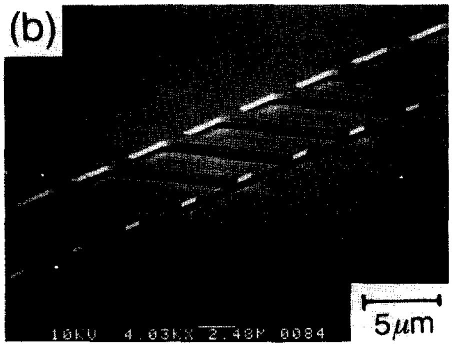

Fig. 2. SEM micrograph of comb-shaped lateral FEA.

μm-thick niobium (Nb) and the emitter-to-gate spacing is $g=0.5$ μm.

Typical current-voltage characteristic of the present FEA is shown in Fig. 3. In the experiment, the emitter is connected to the ground through a serial resistor R_E (110 kΩ). As shown in the figure, the emission current abruptly increases with the gate voltage and reaches about 2 μA/tip at $V_{G'}=110$ V. The reverse current is much lower than the forward current and is less than the resolution limit (1 nA) of an ammeter used. Fig. 4 shows a typical emission stability measured at a pressure of 2×10^{-7} Pa. The short- and long-term fluctuations are less than ±2%/min and ±10%/60 h of the total emission current, respectively.

3. Applications

The present FEA operates as a rectifier because the reverse resistance is much higher than the forward one. Fig. 5 shows a typical rectification chara-

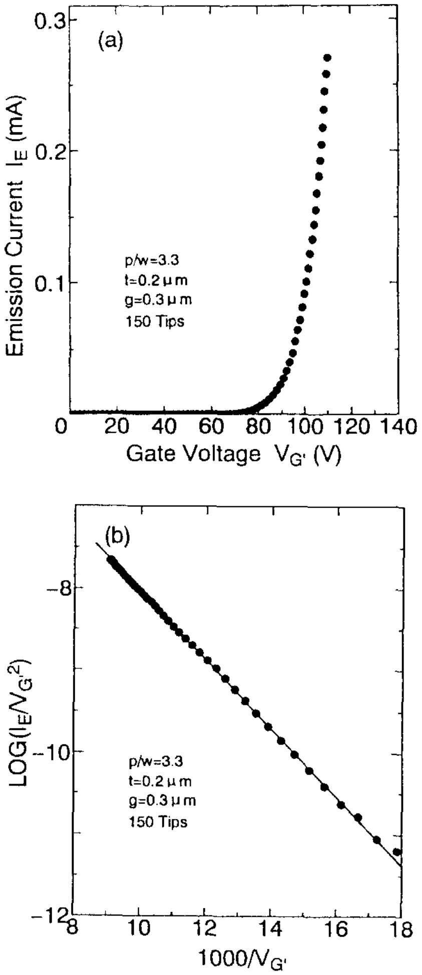

Fig. 3. Current-volgate characteristics of the comb-shaped FEA: (a) in linear scale and (b) in Fowler-Nordheim plot.

cteristic observed with an oscillascope. In the experiment, AC-voltage (100 V, 50 Hz) is applied to the gate electrode and the voltage drop across the resistor R_E is monitored. The input AC-signal is well rectified and the width of the current signal is considerably squeezed because of the strong nonlinear emission property of the FEA.

Ultrafast and radiation-resistant device is a promising application target of vacuum microelectronics. Fig. 6 shows a cross-sectional SEM micrograph of a triode fabricated with the comb-shaped FEA[5]. The present triode consists of the comb-shaped FEA of 0.25 μm-thick W film, an anode of

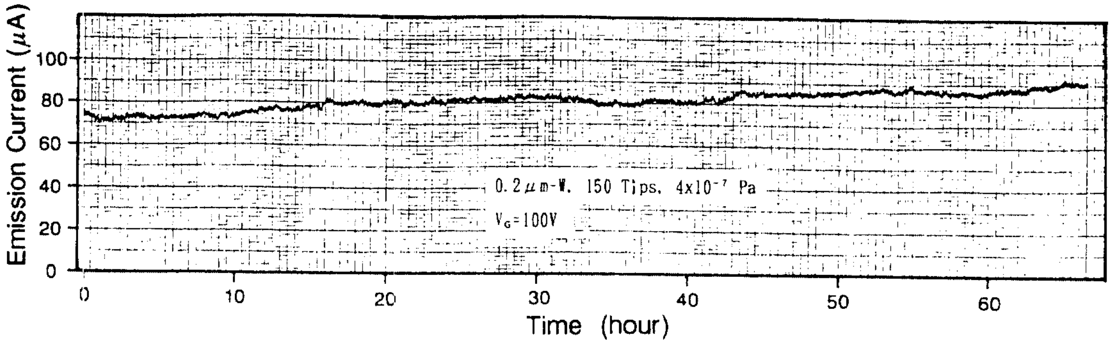

Fig. 4. An example of emission current fluctuations.

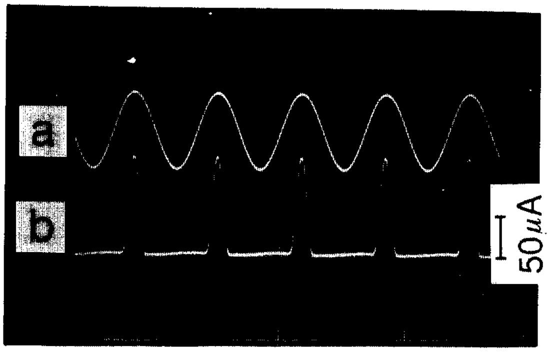

Fig. 5. Rectification characteristic. Upper wave is input signal (AC-100 V), the lower is emission current.

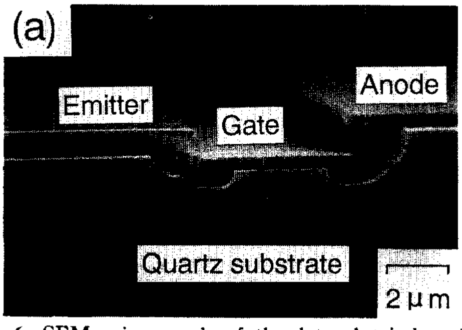

Fig. 6. SEM micrograph of the lateral triode with a com-shaped FEA.

0.5 μm-thick Nb/W film and a gate of 0.5 μm-thick Nb film. The gate is formed by a self-aligned technique on a groove located between the emitter and the anode. The emitter has 150 rectangular tips with 3 μm-wide (w) edges and 9 μm pitch (p): $p/w=3$. The emitter-to-anode distance D and the emitter-to-gate spacing g were $D=5$ μm and $g=0.5$ μm, respectively.

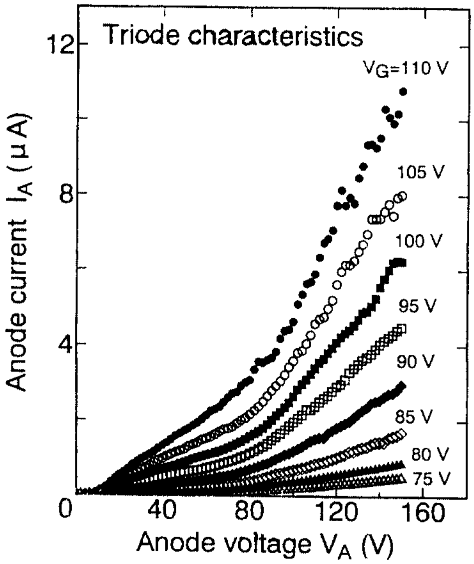

Fig. 7. Triode characteristics.

Fig. 7 shows an example of triode characteristics. As shown in the figure, the anode current I_A increases with the anode voltage. The transconductance estimated roughly from this result is about 0.8 μS at $V_G=110$ V and $V_A=150$ V. For further improvement of the performance, the emitter current and the anode current fraction should be increased by reducing the device dimensions, especially the emitter-to-anode spacing.

For display application, vertical FEAs are believed to be more suitable than lateral FEAs[6]. However, it is easy to make a vacuum fluorescent display (VFD) with the comb-shaped lateral FEA. A photograph of a prototype VFD made with the

Fig. 8. Photograph of prototype VFD under operation.

comb-shaped FEA is shown in Fig. 8[7]. The present VFD is vacuum sealed and operates in atmospheric ambient. The voltages applied to the gate and the fluorescent area are AC-110 V and AC-300 V, respectively. Fluorescent material is commercially available ZnO : Zn.

Magnetic sensor is one of the promising applications of FEAs. The velocity of electrons is easily accelerated in vacuum up to the order of 10^8 cm/s, which is about 100 times larger than the saturation velocity in semiconductor. This fact leads to a considerable increase of sensitivity of the vacuum magnetic sensor compared to conventional semiconductor sensors. From a preliminary experiment, the sensitivity of the vacuum magnetic sensor is about 20 times higher than the GaAs sensor[8].

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