AN RF-MEMS DEVICE WITH A LATERAL FIELD-EMISSION DETECTOR

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ABSTRACT

We propose a new device that utilizes the field-emission effect as a signal-detecting mechanism for RF-MEMS (radio-frequency micro electro mechanical systems) applications. The device consists of a micro electromechanical resonator of BPF (band-pass filter) characteristics and a pair of silicon tips for field-emission, both of which are monolithically integrated by the silicon micromachining technology. The present paper will show a complete set of experimental results on the field-emission current that was controlled by the micromechanical structure, including the latest report on improved fabrication processes for sharper emission tips.

Keywords: RF-MEMS, Field Emission, Micro-oscillator

INTRODUCTION

The new approach proposed here differs from the conventional RF-MEMS devices [1-2] that use capacitive coupling for both excitation and detection of micromechanical resonators. In such devices, dynamic capacitance becomes extremely small (in the femto Farad range) with decreasing device size, and it is generally difficult to overcome the relatively large parasitic capacitance. On the other hand, field-emission current increases with reducing the device size (i.e. emission gap). For this reason, we have employed the field-emission mechanism to detect the nanometric motion of resonators.

A conceptual operation principle is illustrated in Fig. 1. A silicon-micromachined resonator is located between the sharp silicon tips with a mechanically movable tip lying in the path of the field-emission current. The resonator is electrically biased to scan the electron beam when it oscillates at the resonant frequency; the electrons that come through a screening aperture are finally detected by the anode, by which a signal component of the particular frequency is band-pass filtered.

FABRICATION

The fabrication process is shown in Fig. 2. The device structures were made of a silicon-on-insulator (SOI) wafer (10-μm-SOI / 2-μm-buried-oxide / 625-μm-substrate). Precursor shapes of tips were formed by the high-aspect-ratio dry etching of the SOI layer, and the tips were sharpened by the anisotropic wet etching of silicon in a TMAH (tetra-methyl ammonium hydroxide) solution. The micromechanical oscillator was produced at the same time. The SEM pictures of the fabricated the 2nd generation resonator-integrated device is shown in Fig. 3.

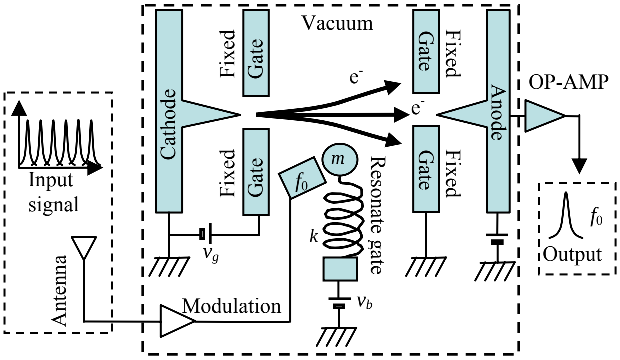

Fig. 1. Conceptual drawing of the proposed field emission MEMS device that works as a band-pass filter. Parameters f_0, k, v_g, and v_b are the modulated frequency, spring constant of the resonator, gate voltage, and bias voltage, respectively.

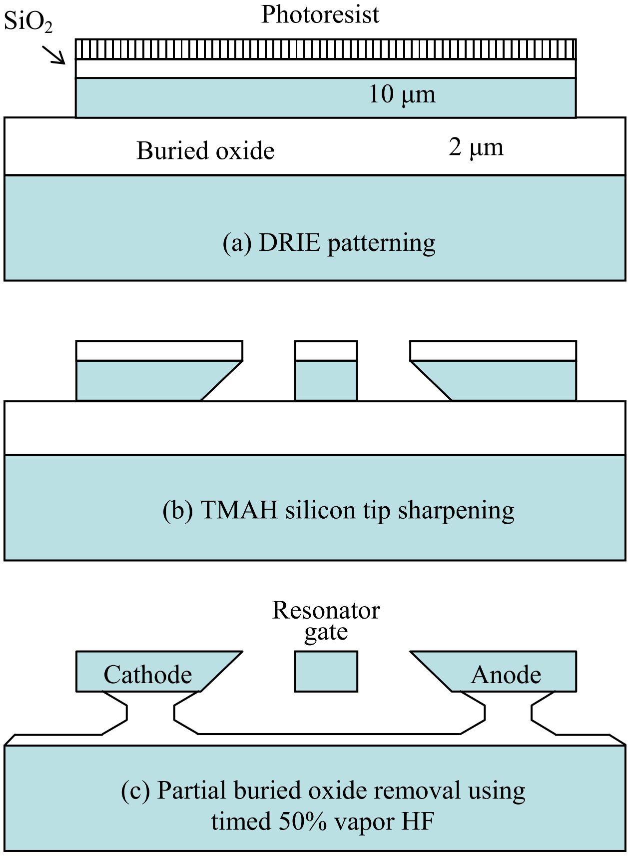

Fig. 2. Fabrication process of the FE tips integrated with a MEMS oscillator. A 10-μm-SOI wafer is patterned by the combination of anisotropic dry and wet etching.

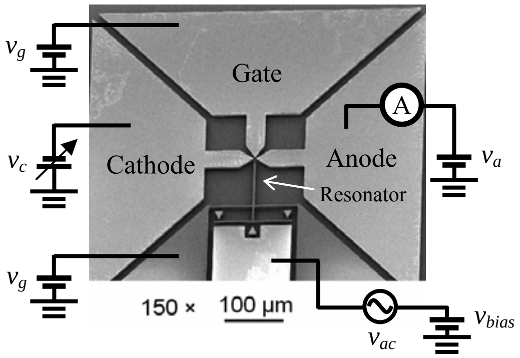

Fig. 3. SEM picture of the entire 2nd generation device integrated with a MEMS resonator.

RESALT AND DISCUSSION

To verify the field emission effect, the current-voltage (I-V) characteristic curves of the device under a well-defined vacuum condition (2×10^{-8} Torr) are to be obtained. The preliminary result of field-emission current was observed to be 4 nA at a differential bias voltage of 300 V with a sample of a 5-μm-gap between the tips (Fig.4. and 5.). After tailoring the device design and fabrication conditions, the gap was reduced to 3 μm, and field-emission current was over 90 nA with a bias voltage of 240 V (Fig.6.). Field-emission was confirmed by the fairly good fitting with the Fowler-Nordheim (FN) plot [3]. The effective emission cross-section α and the electron multiplication coefficient β were estimated to be 1.1×10^{-13} m^2 and 5.8×10^5 m^{-1}, respectively. The field-emission performance could be further improved by adopting materials of lower work functions.

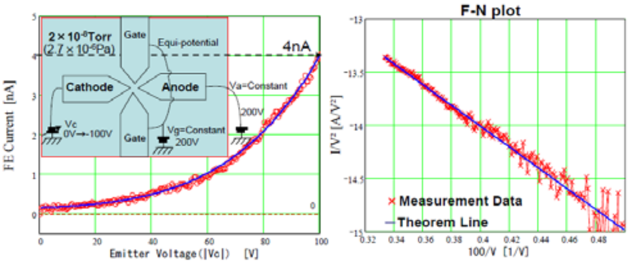

Fig. 4a. I-V curve of a preliminary device without mechanical actuator. Anode voltage v_a and the gate voltages are equipotential at 200 V. Cathode voltage v_c decreases between 0 to -100V. Fig. 4b. The I-V relation can be rearranged to obtain the FN plot. A straight line clearly shows that field emission occurred.

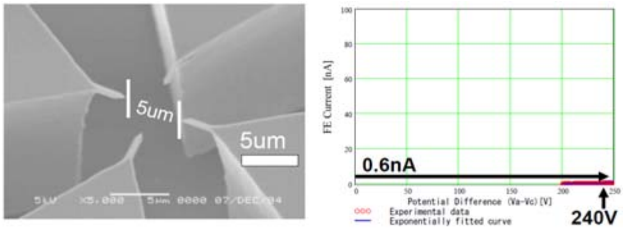

Fig. 5. SEM image of 5-μm-gap tips and the I-V characteristics. FE current was as small as 0.6nA at 240V.

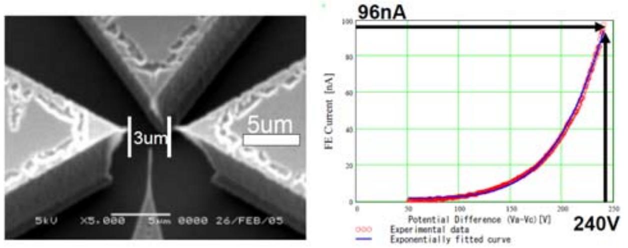

Fig. 6. SEM image of shorter gap (3 μm). FE current has been improved 160-fold.

Modulated field-emission current was also experimentally observed by electromechanically exciting the resonator. Due to the limited frequency range of the apparatus used, we only performed the experiment in the low frequency range (DC ~ 100 kHz). The experimental results to date have shown a proof-of-concept of the RF-MEMS device with the field-emission sensing. New devices of higher frequency range are under investigation.

CONCLUSION

We have reported a new concept of nano-oscillation detection mechanism using the field emission current that could be used as a band-pass filter of radio-frequency devices. A pair of sharp tips and a micromechanical resonator were integrated into a single chip by the silicon micromachining technology. FE current was observed and verified by the fitting to the FN plots. For the full implementation as a monolithic RF-MEMS resonator, chip-level vacuum package is under development. Fabrication processes are to be improved for lower operation voltages by using tip-coating metals of lower work functions.

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