Feasibility Study on Field-Emission Nano-tip for Sensors

C.K. Yang, E. van der Drift, P.J. French
Electronic Instrumentation Laboratory, TU Delft
Mekelweg 4, 2628 CD, Delft, the Netherlands.
Phone: +31 (0)15 2786518 285 Fax: +31 (0)15 2785755
E-mail: c.k.yang@tudelft.nl

Abstract—**Sub-micron cantilever detection using field emission current as sensing parameter has been proposed in previous SAFE conference. In this paper we present our further research on the topic, with improvements in concept design, preliminary simulations and measurement setups. Challenges in emission current measurement are further discussed in detail, and possible solutions are proposed.**

Keywords— **Field emission, microresonators, sensors, NMES.**

I. INTRODUCTION

Nanometre scaled cantilevers have been popular NEMS research topic over the past few years, mainly due to their sensitivity and fast responses. In most state-of-art research centers, properties of these sub-micron cantilevers are measured using either optical interferometry or magnetomotive techniques [1]. A different approach however has been proposed lately; it is based on a tip field emission source that is fabricated under the resonator, the tip emits electrons according to the movement of the resonator and the resonator collects the emitted electrons. Concept devices were fabricated and challenges were discussed in the previous paper [2]. In this paper, improvements and a further study on the feasibility of the proposed concept, based on both electrical and mechanical simulations, is presented. Measurements system is also devised to test the fabricated devices and further investigate the characteristics of the technique.

II. A REVISED CONCEPT DESIGN

In the previous design, a field emission tip is placed beneath a resonating cantilever while bias voltage is applied on both structures. The bias voltage is essential to create an electric field for the extraction of the electrons from the tip. However, for field emission to occur, a typical extraction voltage of at least 10V and a gap distance of less than 1μm is required. The potential field created by the extraction bias will also cause a strong coulomb force attracting the cantilever towards the substrate and crashing the tip.

Due to this unavoidable problem, we revised our concept and added a gate structure to the design. Shown in Fig. 1 is the gate layer in between the tip and the cantilever.

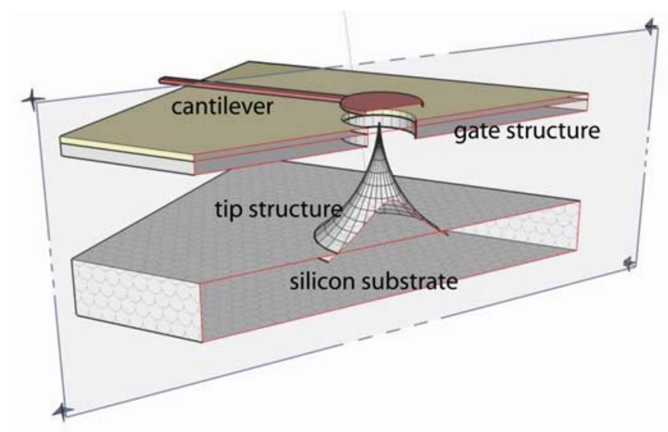


Figure 1. Revised concept design, an additional gate layer is placed between the tip and the cantilever; the gate will be biased to act as field emission extractor, as well as provide physical protection for the tip.

The gate layer will be fabricated near to the tip and with small aperture. This will allow the gate to act as field emission controller, extracting electron from the tip and control the emission intensity by changing its bias voltage. Previous researches on field emission triodes showed such scheme is well possible and can furthermore effectively lower the bias voltage needed to startup the emission [3].

III. SIMULATIONS

A. Electric field simulation

The concept of gate layer as electron extractor can be clearly illustrated by electric field distribution simulation. Shown in Fig. 2a is the cross-section view of a cantilever with a tip under. The lines around the structures are equipotential field lines; note that the lines are especially dense near the end of the tip, which is the field enhancement effect and corresponds to the factor β of the Fowler-Nordheim equation [4][5]. The region between the cantilever and the tip has a very dense field distribution, which in turn creates a large electrostatic force that will eventually attract the cantilever towards crashing the tip.

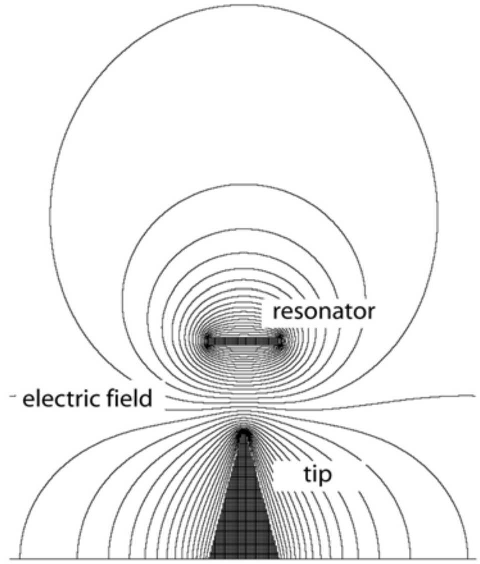
In Fig. 2b, a gate layer is added. We applied a bias between the gate layer and the tip, while keeping the cantilever at the same bias voltage as the gate. The field distribution in this case, is mostly constrained between the tip and the fixed gate structure. Very little field acts on the cantilever through the aperture of the gate, which can be neglected. We can thus fabricate a gate layer with small aperture and near to the tip, such that possibly less than 10V of extraction bias is needed.

B. Electron trajectory simulation

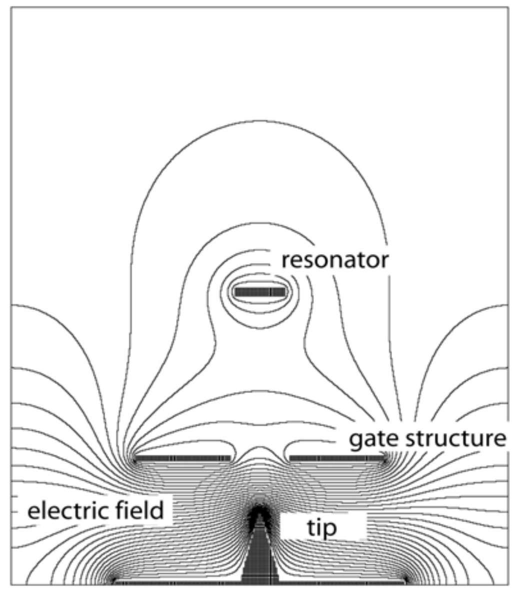
In order to analyze the effect of gate layer on the trajectory of the electron, we used a finite difference method program, Simion 3D (version 7.0), to simulate running path of charged particles in electric field environment. Fig. 3a illustrates the case of the original concept, while Fig. 3b shows when gate layer is added. The bias condition is identical to the field simulation in Fig.2a and 2b. When the cantilever and the gate are equally biased, emission electron of certain angle will be lost as shown in Fig. 3b. Not shown in the figure however, is the electrons that will travel to the gate, causing emission current leakage between the tip and the gate. The gate current in this case, has been experimentally studied and can be neglected by carefully selecting bias voltage and distance [6][7].

C. Design challenge of gated concept

The challenge in the gate design is the optimization of the cantilever-gate-tip distances and the bias voltages. On one hand, the cantilever should be affected by the emission bias as less as possible; on the other hand, the cantilever has to create enough emission deviation in order to induce emission current peaks when resonating. Therefore a compromise has to be made between the



a.



b

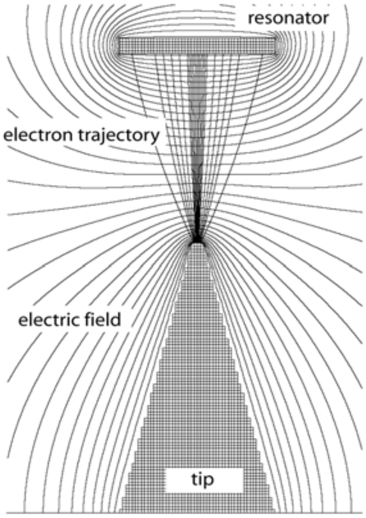
Figure 2a. Equipotential electric field simulation of cantilever-tip concept. Figure 2b. equipotential electric field simulation of cantilever-gate-tip concept. Simulation ran on Simion3D, version 7.0.

cantilever's mechanical sensitivity and the tip's emission sensitivity.

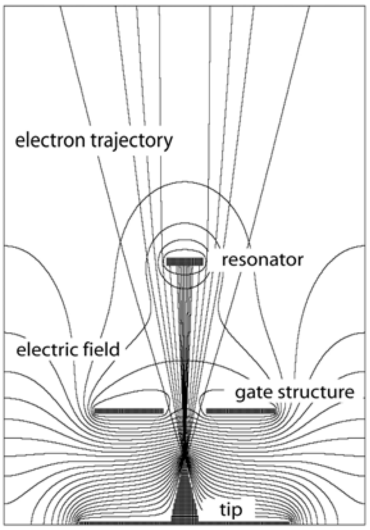
IV. MEASUREMENTS

A. Setup

To understand the relationship between electrode distance and emission current, we require a controllable mechanical displacement system in nanometer resolution, and a distance measurement device to determine the electrodes' absolute distance. To do this, we replaced our cantilever with tungsten probe and mount the whole tip device onto a probe station stage.



a.



b.

Figure 3a. Electron trajectories of the tip-cantilever concept. Figure 3b. Electron trajectories of the tip-gate-cantilever concept.

We used a Jeol SEM system integrated with a Zyvex S100 nanomanipulator system as the probe station. The Zyvex piezo drives provide the precision displacement needed (resolution down to 5nm) while the SEM system is used to observe and measure the actual distances. Fig. 4 shows the measurement probe stage and Fig. 5 shows an example of measurement SEM pictures. Fig. 6 shows the schematic diagram of the measurement circuit.

B. Results

Using the Zyvex system, we were able to obtain measurable field emission when the probe is brought close to within 2μm of the tip. Applying a bias voltage raging from –5V to -2V, while measuring the current flow, we plotted the I-V curve and further extracted the FN plot. Fig. 7 shows the FN plot and the schematic diagram of the measurement connection.

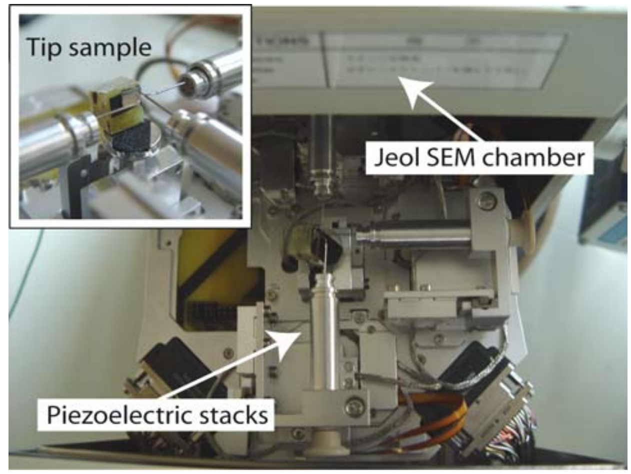


Figure 4. Zyvex nanomanipulator stage, integrated in a Jeol SEM system. Inset shows the the tungsten probes and the sample with tip structures.

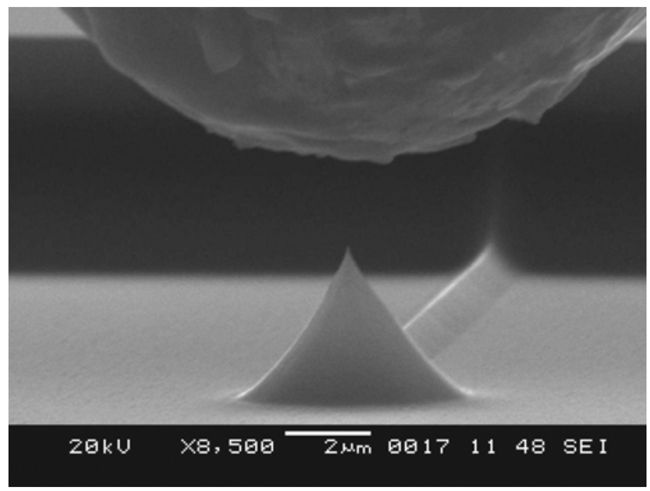


Figure 5. Example of SEM measurement of the tip-to-probe distance.

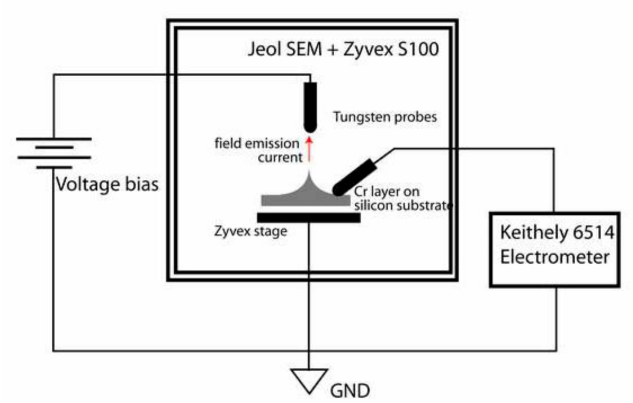


Figure 6. Measurement connection. A Keithley 6514 electrometer is used to perform low current measurement.

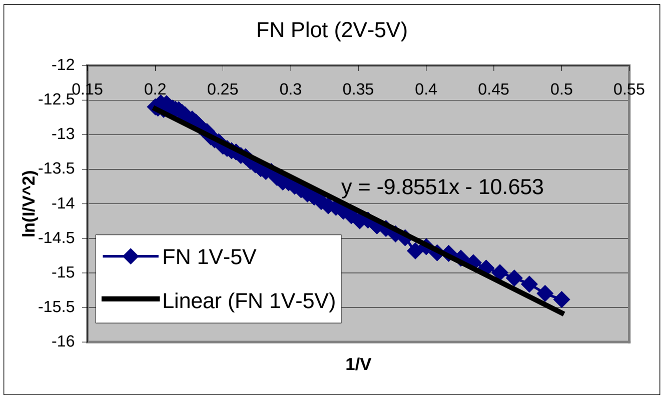


Figure 7. Fowler-Nordheim plot of the field emission measured using the Zyvex system.

From the FN plot we were able to extract the field enhancement factor β = 1.4146e9 (1/m) and emission area α = 3.8932e-19 (m2). The straight-line relationship in the FN plot suggested that the current measured has a typical field emission exponential relation. However the β factor extracted is orders of magnitude larger, while the emitting area α is smaller than expected. The cause of such inconsistency has not been determined yet. Measurements are performed when the SEM source is turned off and blanked. In our observation however, the SEM electron source only introduced an offset to the measured current.

Measurement of emission current with varying probe distance has also been performed. However due to the instability and inconsistent emission performance, concrete result has not been obtained yet.

C. *Challenges*

The main challenge in field emission measurement is in its low current and high resistance nature. Emission current of pA is typical for a single tip emission, while bias voltage of a few volts is required. Hence leakage current from cables and stage can easily overwhelm the emission signal, saturate the current amplifier. Furthermore, parasitic capacitances in the system easily cause a long charging-discharging time constant. The effect of leakage and capacitance can be diminished by shielding the cables and guarding the measurement device, however this can only be achieved by altering the wiring of Zyvex system and SEM hardware.

V. Conclusion

An improvement design of the field emission sensing approach has been proposed. Simulations of the added gate layer have been performed. Both the electric field distribution and the electron trajectory are studied. Furthermore, experiment devices has been setup to obtain the relationship between cantilever displacement and the emission current, however more concrete results are yet to be extracted. Finally, the challenges in testing and measuring the field emission current using the setup were shortly discussed.

References

[1] A.N. Cleland and M.L. Roukes "Fabrication of high frequency nanometer scale mechanical resonators from bulk Si crystals," *Appl. Phys. Lett.* **69** (18) 2653-55, 1996.

[2] C.K. Yang, G. Pandraud, E.vd Drift and P.J. French, "Field-Emission Nano-tip for Microresonator Detections," *Proceedings of 8th SAFE Workshop*, pp181-5, Veldhoven, 2005.

[3] D. G. Pflug, M. Schattenburg, H. I. Smith, and A. I. Akinwande, "100 nm aperture field-emitter arrays for low-voltage applications," in IEDMTech. Dig., San Francisco, CA , pp. 855-858, Dec. 1998.

[4] R. H. Fowler, F. R. S., and L. Nordheim, "Electron emission in intense electric fields," *Proc. R. Soc. Lond. A*, vol. 119, pp. 173-181, 1928.

[5] P. H. Cutler et al,"Theory of electron emission in high fields from atomically sharp emitters: Validity of the Fowler-Nordheim equation," *J. Vac. Sci. Technol. B*, vol. 11(2), pp. 387-391, Apr. 1993.

[6] H.H. Busta, B.J. Zimmerman, M.C. Tringides and C.A. Spindt, "DC I-V characteristics of field emitter triodes," *IEEE trans. On Elect. Dev* **28**(11), 1991.

[7] C.W. Lu and C.L. Lee, "A physical simulation model for field emission triode," *IEEE Trans. On Elect. Dev.* **45**(10), 1998.