Final Report of AOARD 09-4122

# Multi-dimensional modeling of electron field emission with and without laser excitation

PI: Prof. ANG Lay-Kee
Division of Microelectronics
School of Electrical and Electronic
Nanyang Technological University, Singapore 639798
Email: elkang@ntu.edu.sg
Telephone: 65- 6790-4228 (office) 6793-3318 (fax)
Website: http://www.ntu.edu.sg/home/elkang

The production of electron beam of high brightness and low emittance is critical for a variety of scientific and technological applications such as high power vacuum coherent radiation source such as microwave sources, free electron lasers (FEL) and electron imaging system. The focus is to have a robust cathode using field emission mechanism based on the process of electron tunneling from a metal's surface, which is also known as Fowler Nordheim (FN) law. When a laser is used to excite the electron emission, the mechanism is known as the Fowler-Dubridge (FD) model. In this project, we aim to improve the basic of fundamental understandings of the electron emission process (related to FN and FD models) by developing multi-dimensional (2D or 3D) models.

In this short report, we will present the topics supported in this grant,

## 1. Quantum Shot noise suppression of field emission – 2D dimensional model

We have successfully created a two-dimensional (2D) nonuniform model to calculate the quantum shot noise suppression (or Fano factor) for electron field emission from a single field emitter of two different shapes: Lorentzian and prolate spheroidal. Between them, the Lorentzian field emitter has a larger shot noise suppression. For a given sharp emitter at a fixed work function, there is a minimum value of the Fano factor, which is independent of the geometrical sharpness of the emitter, and it increases with larger work function. Comparison with the one-dimensional uniform model has implied that prior results had overestimated the shot noise suppression. The results was published in the Journal of Applied Physics [JAP 107, 106103 (2010)]. In Fig. 1, we show the calculated Fano factor of (a) Lorentzian and (b) prolate spheroidal type for a single Ba field emitter with a work function 2.48 eV at different sharpness: (a) h/w and (b) d/a.

# Report Documentation Page

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14. ABSTRACT
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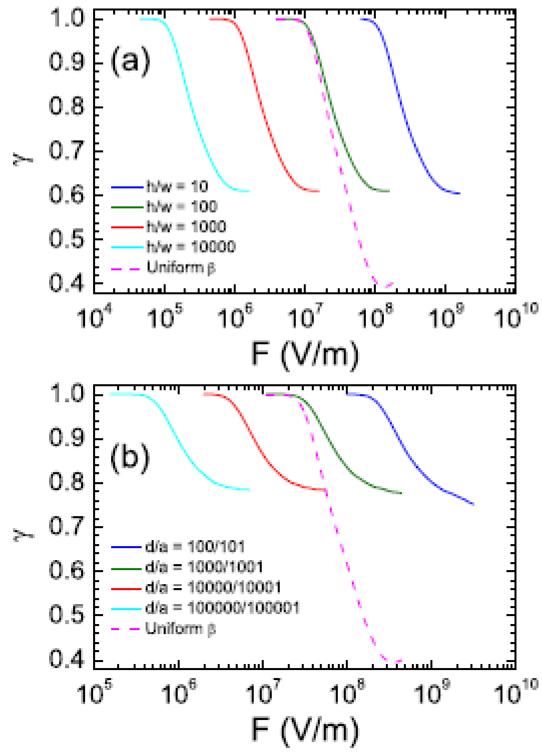


Fig. 1 Fano factor γ as a function of applied E field F

## 2. Higher dimensional protrusive Child-Langmuir (CL) law

The current understanding of CL law is restricted to an uniform flat surface with a finite emission area. With finite emission area, the enhancement over the 1D limit is like 1 + a / (W/D) where a is a numerical constant, and W/D ( is the ratio of width of the emission area over the gap spacing). In this topic, we have extended the 2D or 3D CL law to include the sharpness of the emitter (in terms of height) and nonuniform emission over the surface. Our preliminary results show that the enhancement factor will converge to a value for small emission area or very sharp emitters as in Fig. 2 below for an emitter with a work function of 4 eV for **:** Lorentzian (circle) and hyberboloid (triangle). The results have been submitted for journal publication.

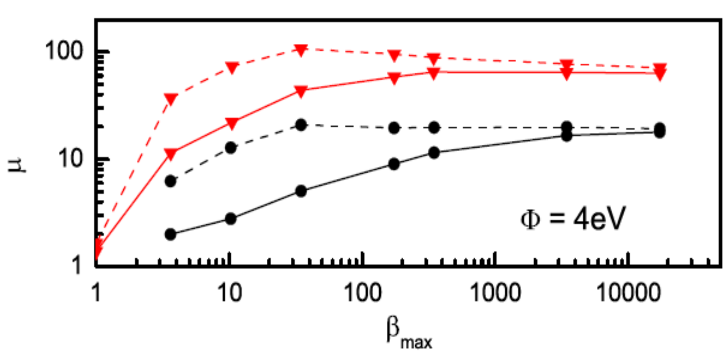


Fig.2 Enhancement of the 1D CL law as a function of field enhancement factor

3. **Single electron limit of Child Langmuir law under laser excitation**

   In this topic, we consider ultrafast laser is able to excite the emission of electron from a metal surface in discrete limit. In this limit, the electron will emit in the form of oscillation at low voltage. At high voltage, the oscillation will damp to become a steady state condition. The average current density is closed to the classical CL law. The results are now in preparation for journal submission.

4. **Multi-dimensional models of CL law based on capacitance formulation.**

   The traditional 1D CL law can be reformulated using capacitance model. In this topic, we are interested to use the same concept to reapprove the 2D CL law but using 2D capacitance model. The research on this topic is still on-going.

5. **Electron field emission model of a single layer graphene.**

   At the end of this project, we have learned of great research interests of field emission from a new material – single layer graphene. In this topic, we have started to develop new model to describe the emission process, and our preliminary results indicate that the classical FN law is not valid. The resesearch on this topic is still on-going, and it will continue under the support of a new grant by AOARD 10-4110.

## SUMMARY

Within the 12 months of this grant, we have successfully developed new 2D or 3D models of electron field emission in the limit of space charge limited current. This study has provided important insights in the nano-physics of electron emission and electron transport in a broad area of quantum vacuum nano-electronics. Some of the on-going research topics will be continued under a new AOARD grant 10-4110.