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STUDY THE EFFECTS OF CHARGED PARTICLE RADIATION ON GRAVITATIONAL SENSORS IN SPACE

Final Report

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NAGW-4863

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5-7-99

Introduction

Space-flight charging of free floating masses poses an unusual problem--how can one control charge on the object without exerting a significant force on it? One approach is to make contact to the object with a fine wire. However, for many precision applications no physical contact is permissible, so charge must be conveyed in a more sophisticated manner. One method has already been developed: GP-B uses an ultraviolet photo-emission system described in ref 1. This system meets the experiment requirements, yet poses a number of constraints, including high power dissipation (~10 W peak, ~1 W average), low current output (~10^{-13} A), and potential reliability problems associated with fiber optics system and the UV source. The aim of the current research is to improve this situation and, if possible, develop a more rugged and lower power alternative, usable in a wide range of situations.

An potential alternative to the UV electron source is a Spindt-type field emission cathode. These consist of an array of extremely sharp silicon tips mounted in a standard IC package with provision for biasing them relative to the case potential. They are attractive as electron sources for space applications due to their low power consumption (10^{-5} W), high current levels (10^{-9} to 10^{-5} A), and the absence of mechanical switching. Unfortunately, existing cathodes require special handling to avoid contamination and gas absorption. These contaminants can cause severe current fluctuations and eventual destruction of the cathode tips. Another potential drawback is the absence of any data indicating the possibility of bipolar current flow. This capability is needed because of the large uncertainties in the net charge transfer from cosmic rays to a free floating mass in space. More recent devices reduce the current fluctuations and destructive arcing by mounting the tips on a resistive substrate rather than a good conductor. This effectively wires a resistor to each individual tip, providing a current limit and thus greatly reducing the possibility of destructive arcing through an individual tip. An issue with this resistive layer is its range of operating temperatures.

From the experience with the GP-B system, we hypothesized about using secondary electron emission for control of net charge transfer to an object. An important goal of the testing described below was to demonstrate the ability to apply both positive and negative charges to the test object from a single emitter.

Activities:

Initially we upgraded an apparatus from the GP-B program to configure it for measurements on the field emitter arrays. The vacuum system was improved, a mounting assembly for the emitter was built and electronics assembled. The apparatus was then operated extensively using a multi-tip field emitter array. A significant amount of data was collected using the emitter cathode with a conducting substrate.

Testing was performed in a custom high-vacuum test station consisting of a stainless steel vacuum chamber equipped with convectron and ionization gauges, conflat high-voltage feedthroughs, and a turbo-molecular pump backed up by a two stage roughing pump. The experimental set up consisted of a collector plate, various grid pieces, and a top biasing plate which housed the cathode itself. This schematic along with electrical wiring is shown in Fig.1. Before testing, the system was baked at ~100°C overnight, and yielded final pressures in the 10^{-10} Torr regime. Each setup was checked for leakage current which was limited to less than 1pA, the noise level in our electronics. Some capacitive leakage was observable when voltages were changed, decaying with a 1 sec time constant.

The primary aim of preliminary testing was to determine the feasibility of removing electrons from the collector surface (generation of positive current, as opposed to negative current in normal operation). To do this, first the set up is tested without any grid, and then various grid geometries are inserted and the results compared with earlier data. These grid geometries are shown in figure 2. The results are described below.

Results and discussion

The first test was to have no grid piece, and attempt to establish the expected straight line Fowler-Nordheim relationship between voltage drop (V(gate) - V(tip)) and current. Our results are shown in fig 3. As can be seen, the data does seem to follow a linear pattern as expected by Fowler-Nordheim theory, but tails off in the higher voltage region. We believe this is due to increased shorting of current to the gate, which causes less of a voltage differential than expected. As the cathode has a near infinite impedance between the tips and the gate, measuring the voltage differential has proven too unreliable with a simple digital voltmeter reading, and further investigation was not appropriate at the time. In this setup, no positive collector current should be observed.

Grid # 1, a mesh, yielded our first indication of positive collector current. This positive current occurred with a grid biasing voltage in the 1 - 4 V range with various biasing potentials on the emitter array. The results are shown in fig 3. Grid # 2 and Grid #3 achieved similar results to the mesh grid, with results shown in fig. 4. Grid #5 also yielded positive current, but smaller in proportion to the earlier grids, and with higher threshold voltages on the grid. Grid #4, a simple setup of two parallel wires, failed to produce positive current.

These results are very encouraging. They indicate that a low grid bias (~1-4V), and a relatively low emitter bias (-100 to -200V) induce electron removal from the collector surface. Additionally, grid geometry seems to allow positive current in most cases, allowing various threshold voltages depending on geometry. We expect that threshold voltage, total current, and overall distance can be controlled by manipulating the grid geometry. In principle, one could optimize this configuration to find the "minimum force" geometry, such that the voltage biasing, surface area, and efficiency of electron removal/addition are accounted for. Rough estimates indicate that a mesh may prove an optimum configuration. We have used these results to settle on two grid geometries for our future work.

Reference:

1. S. Buchman, T. Quinn, G.M. Keiser, D. Gill and T.J. Sumner, *Charge Measurement and Control for the Gravity Probe B Gyroscopes,* Rev. Sci. Instrum. **66,** 120 (1995).

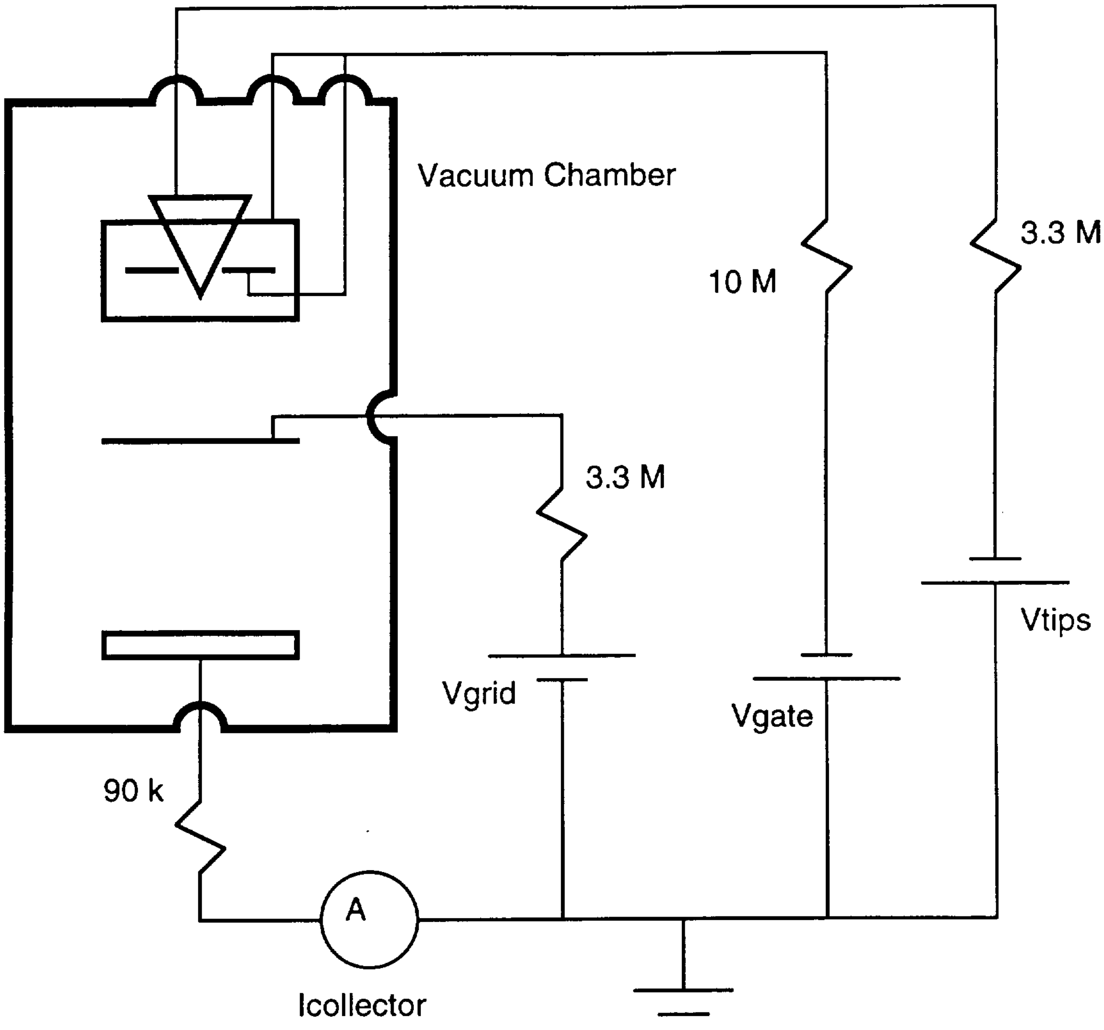

Figure 1: Preliminary testing set-up. Here the resistors are placed in series for protection from arcing. With currents well below 10^{-6} A, we do not expect much of a voltage drop accross any resistor.

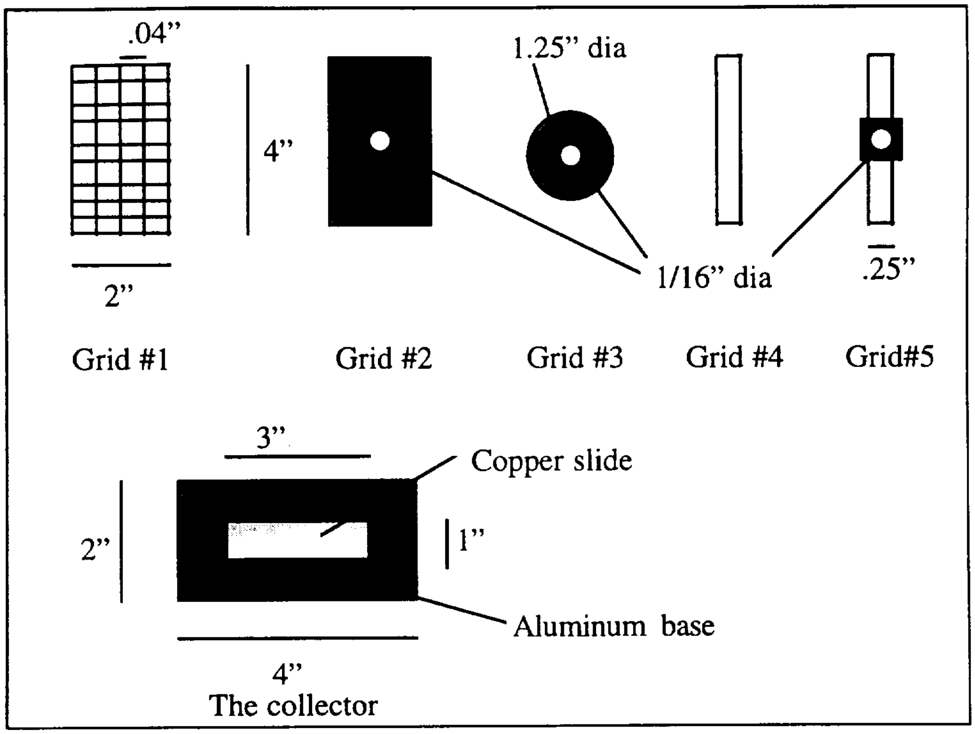

Figure #2: Grid piece and collector geometries.

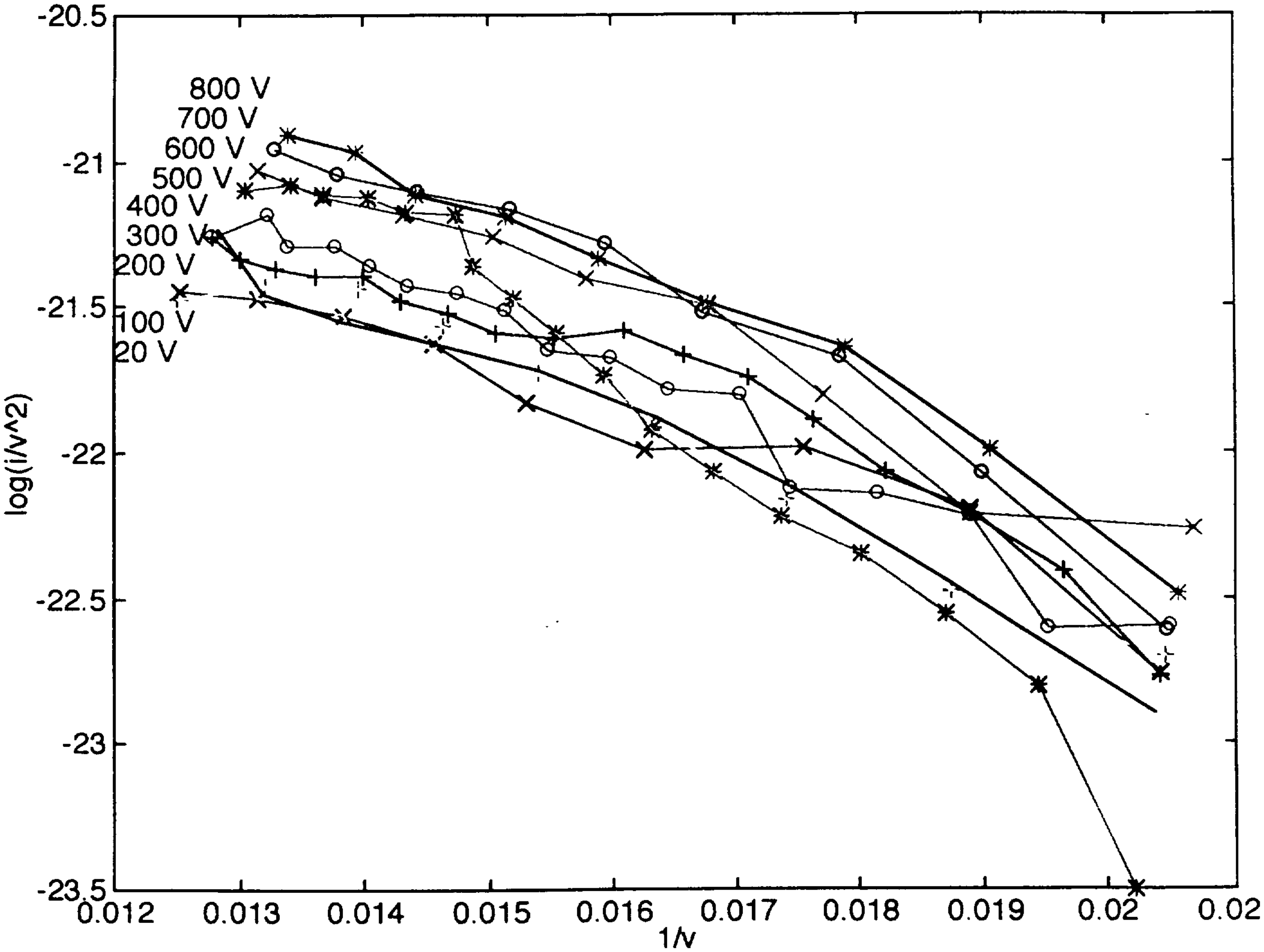

Figure #3: Fowler Nordheim plot for v = Vtips-Vgate, I = current averaged over 500 seconds. Vtips is a corrected value accounting for voltage drop across 3.3M resistor, assuming all emitted current is collected at the collector.

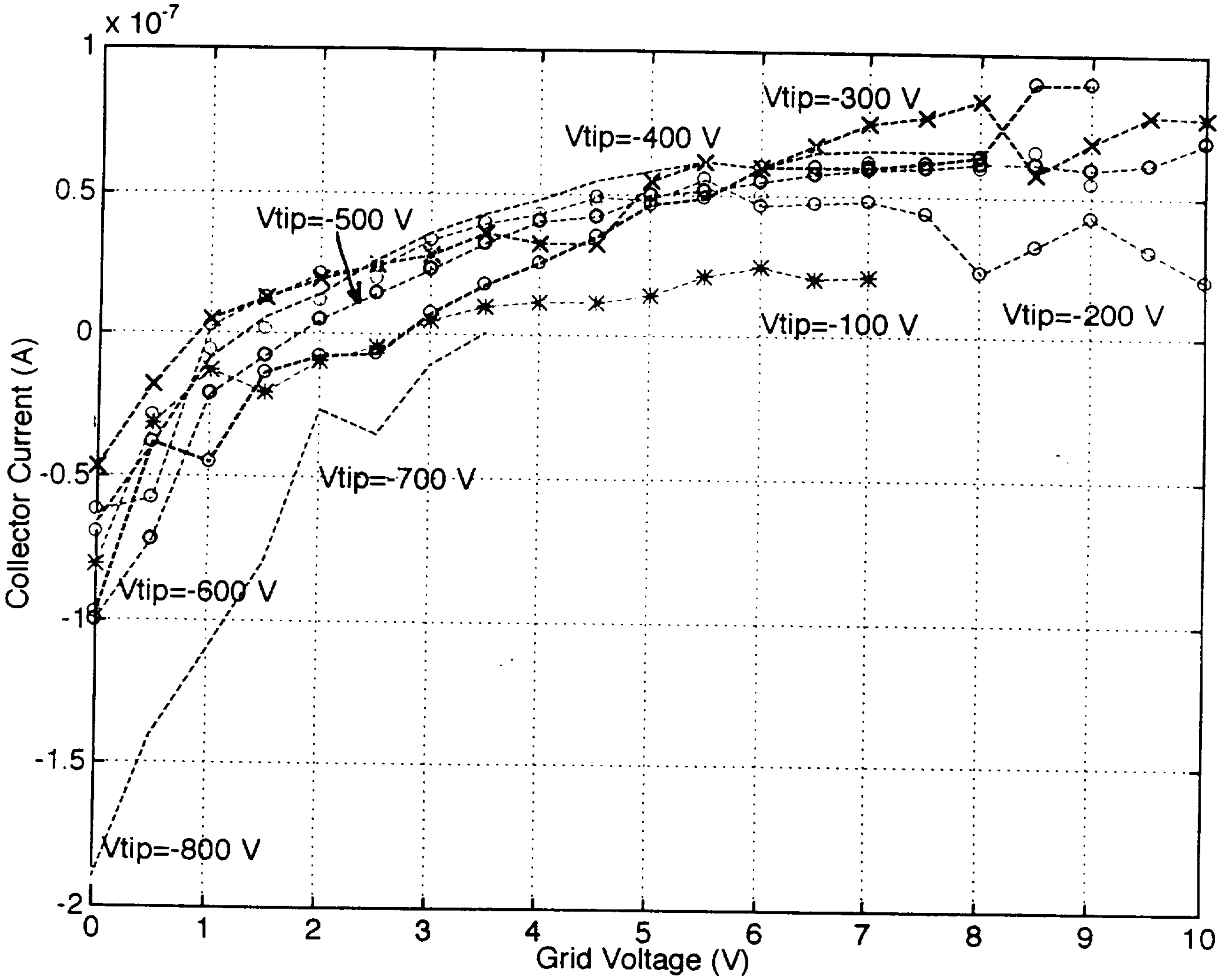

Figure #4: Effect of secondary electron emission for Grid #1 (.04" mesh). Voltage between the tips and the gate maintained at -50V. Notice the collector current changes sign at different voltages associated with different tip potential.

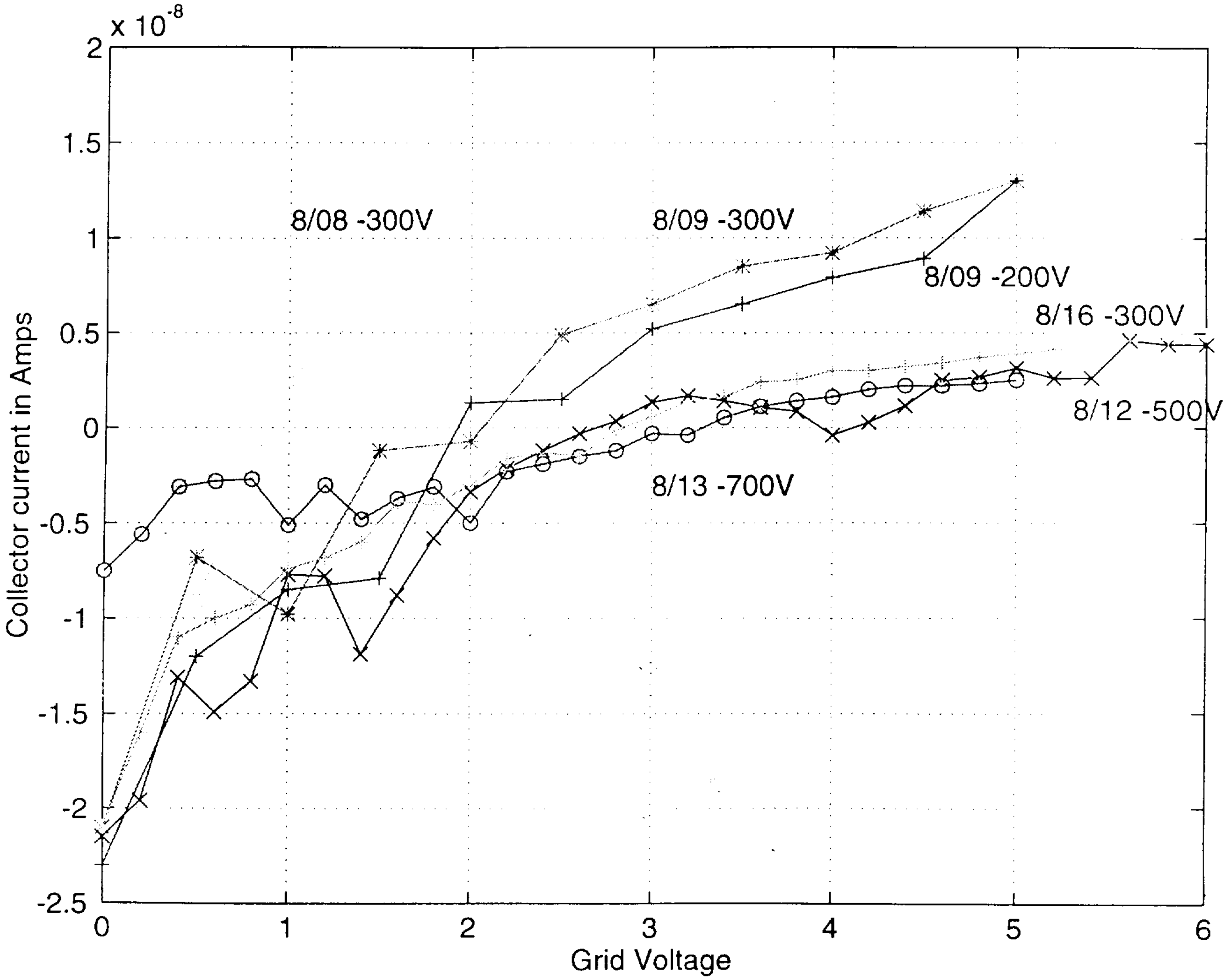

Figure #5: Effect of secondary electron emission for Grid #2 (Plate with 1/16" hole). Voltage between the tips and the gate maintained at -50V. Notice the collector current changes sign at different voltages associated with different tip potential.