Preparation of Field Emission Point (FEP) tips for electron generation at relatively low voltage in a Cryogenic Penning Trap

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Introduction

In a Penning Ion Trap (PIT), superposition of quadrupolar electric field and homogeneous magnetic field trap the charge particles[1]. In VECC-PIT, electrons are trapped and it is generated by applying high voltage to Field Emission Point (FEP). In cryogenic condition, application of high voltage for electron generation is a challenging task.

A FEP tip has been prepared by physicochemical techniques through electrochemical etching. Usually, field emission requires application of high voltage of around 1000 V. But, our specially fabricated FEP tip could generate electrons at nearly 300 V at room temperature.

Preparation of FEP tips

FEP tips are fabricated in electrochemical etching method from polycrystalline tungsten wire [2]. This is an inexpensive method and produces very sharp and symmetric tips. Tungsten (W) has been selected for the FEP material because of low work function, low chemical affinity along with high boiling point and large mechanical strength. Straight tungsten wire with diameter of 539µm diameter is dipped inside the 3M KOH solution. A steel wire of 0.85 mm diameter formed in ring shape of diameter 1 cm acting as counter electrode, is also dipped in the solution. Capillary force formed a meniscus around the tungsten wire. The wire is connected to the positive terminal of 5 V DC power supply and the counter electrode is connected to the ground in order to complete the electrical circuit. Counter electrodes will produce OH^- ions and there will be a concentration gradient of OH^- ion around the tungsten wire. As the etching rate is slower at the top of the meniscus, a neck around the wire will be formed. Further the soluble tungstate ion flows down to the lower part and makes a viscous layer that prevents it from etching. At a point of time, the neck becomes so thin that it cannot sustain the tensile strength of the lower part resulting the fall off lower part and a sharp tip will formed at this neck. This is commonly known as the “drop-off” method. Once the tips were formed, they were first rinsed with distilled water and then cleaned by HF acid. The tips were taken to observe under SEM as shown in Fig. 1. The radius of the tip was measured at 3000X zoom and it was found to be around 139 nm.

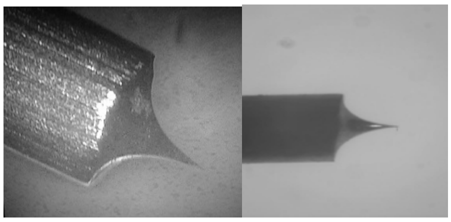

Fig 1: FEP tip fabricated by electrochemical etching process

Preparation of high quality FEP tips require certain precautions [3]. Diameter of the wire should be small. Higher diameter wire will take longer time for etching procedure which may result in etching of the lower part. Etching of lower part may also take place if the concentration of solution is high. In this electrochemical process, H_2 gas is produced near counter electrodes. They make bubble in the solution and distort the meniscus. So the counter electrode should not be dipped fully within the solution. Application of AC voltage will also accelerate the bubble formation. Immersion length of tungsten wire within solution is another important factor in this fabrication procedure. If the immersed length is very small, required tensile strength for drop-off is small. On the other hand, larger immersion length will cause premature drop-off which results in increase of radius of curvature of the tip. In our fabrication, immersed length was optimized to 5mm.

Experimental set up and measurement of Field emission current

The tip is mounted into the tip holder. A teflon plate is placed in front of it and there is a groove where a steel foil of thickness 200 micron is placed. The foil is pressed by a metallic body. The metallic body and the collector plate are separated by a MACOR insulator. All the plates and spacers in front of the tip have holes for electrons to pass away and finally get collected at the metallic plate (As shown in Fig-2).

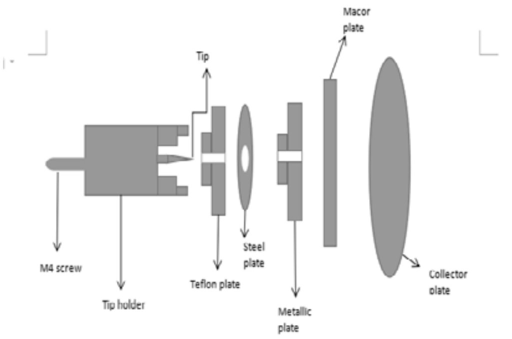

Fig 2: Experimental Schematic to characterize the FEP.

The whole assembly was kept in a chamber and evacuated to a pressure of 4.6 x 10^{-6} mbar. Positive high voltage was applied to the metal foil. Collector plate and FEP was kept at ground potential. In the first operation, field emission was observed at 1200 V. High voltage is needed for the first time emission of electrons. This happens because the emitting surface remains contaminated due to oxidization in air and these oxides and microcrystals increases the tunneling resistance.

On repeated operation, oxides are removed due to sputtering phenomena and electron generation by field emission process takes place at relatively low voltage. We decreased the voltage gradually and obtained nearly 1µA current on application of around 300 V.

The FEP tip was operated several times. The minimum voltage at which we obtained emission current of around 1µA was further decreased. This happened because of self-sputtering process [4] sharpen the tip in each trial resulting in lowering of minimum voltage. In self-sputtering process, emitted electron from FEP tip ionizes the background gas and these positive ions travel backwards to the tip inducing sputtering. Typical emission current obtained with increasing voltage is shown in Fig. 3.

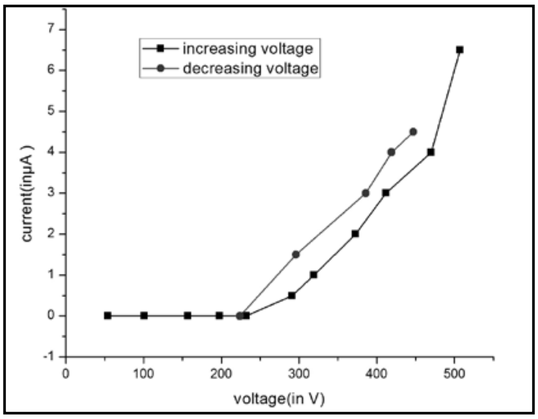

Fig 3: FEP current with voltage

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