Cryogenic thin-film electron emitter

Golokolenov I.A., Khaldeev S.I., Purbeeva E., Zavyalov V.V.

Kapitza Institute for Physical Problems, Moscow, Russia
Moscow Institute of Physics and Technology (MIPT), Moscow, Russia
Higher School of Economics (HSE), Moscow, Russia
hasteak@rambler.ru

Abstract

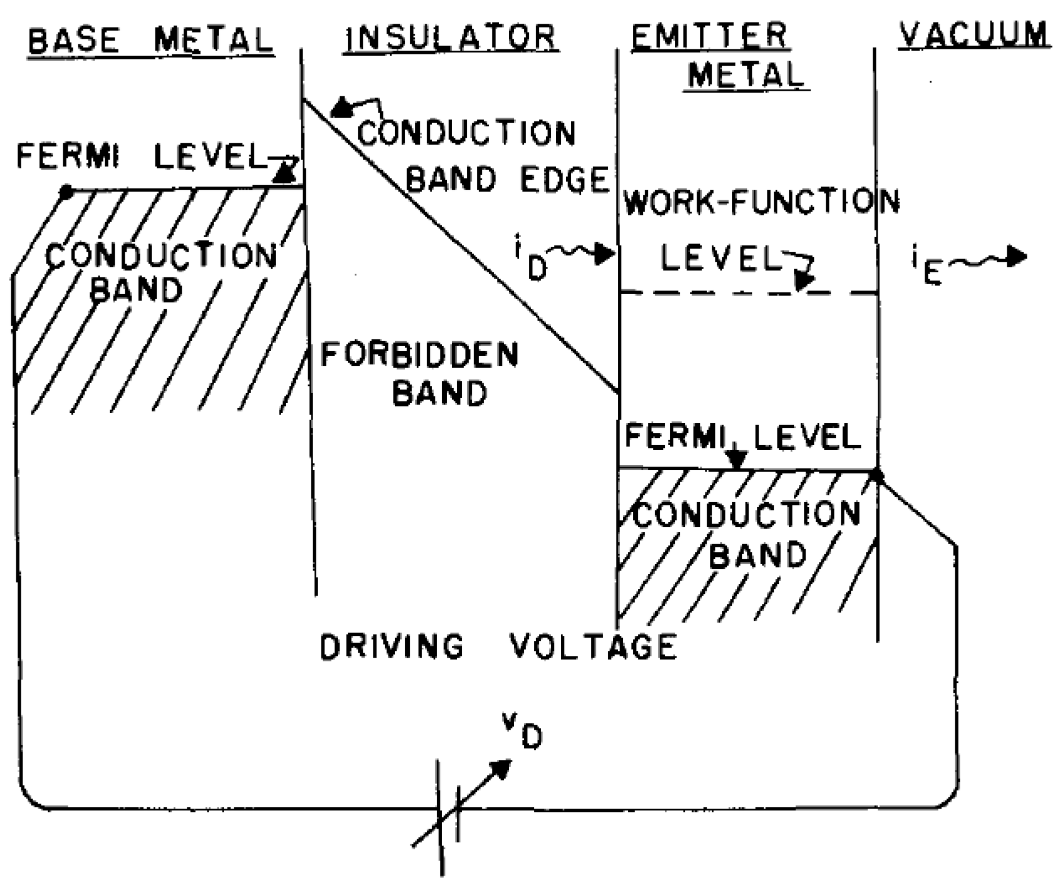
Despite the fact that the electrons in bulk helium were studied for over half a century, observations of new intriguing effects still appear. Alas, the traditional methods of injecting electrons into bulk helium (α-sources, W-thermoemitters, discharge or field emission) lead to the generation of a large number of excitations (ions, dimers, rotons, etc.) and/or thermal flows. As a result, the interpretation of experiments is not simple and sometimes may be questionable. In this respect, the thin-film emitters are more preferable and have been used, for example, for emission of electrons to the helium surface.

1. Introduction

THIN-FILM EMITTER is Metal-Insulator(oxide)-Metal (MOM) structure with extremely thin layer of surface metal. The MOM structure provides small tunnel current via thin oxide layer of Al_2O_3 and tunneled electrons have a chance to move through the top layer of about $100\mathring{A}$ gold film without relaxation and leave the surface of the emitter. With this device we managed to achieve the electron currents $>1nA$ in ^4He gas at $10V$ applied voltage and power of $10\mu W$.

2. Theory

Simplified principle of operation of the emitter described on the energy band diagram below.



Driving voltage applied between two metal layers makes electron able to quantum tunnelling via forbidden band (insulator) without losing any energy for this process, becoming "excited" electron in emitter metal. If the summ of driving voltage and difference between work functions minus dissipated energy is still greater than the work function of top metal when the electron reaches it's surface, this electron can leave the surface and produce the "emission current" such as for photoelectron emission.

3. Sample fabrication

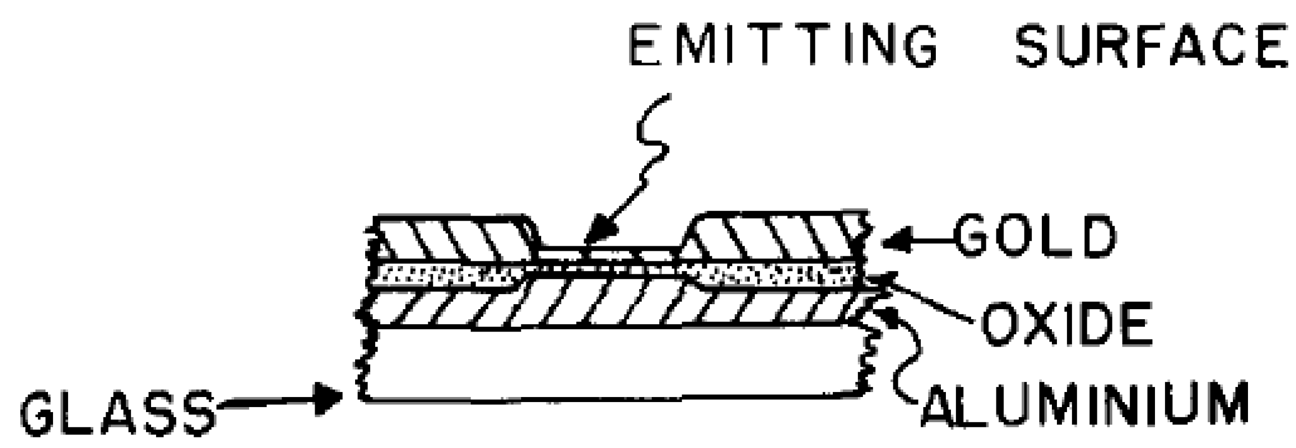
The fabrication of the emitter consists of 3 stages.

The first step is vacuum sputtering of a thick (about $1500\mathring{A}$) layer of base metal. Classic sample is based on aluminum. It is important to properly clear and heat the substrate since aluminum has low adhesion to most substances.

The second step is performing dielectric oxide layer with thickness of $30-150\mathring{A}$, depends on method, material and expecting results. The most preferred method for aluminum-based samples is wet anodization in tartrate solutions.

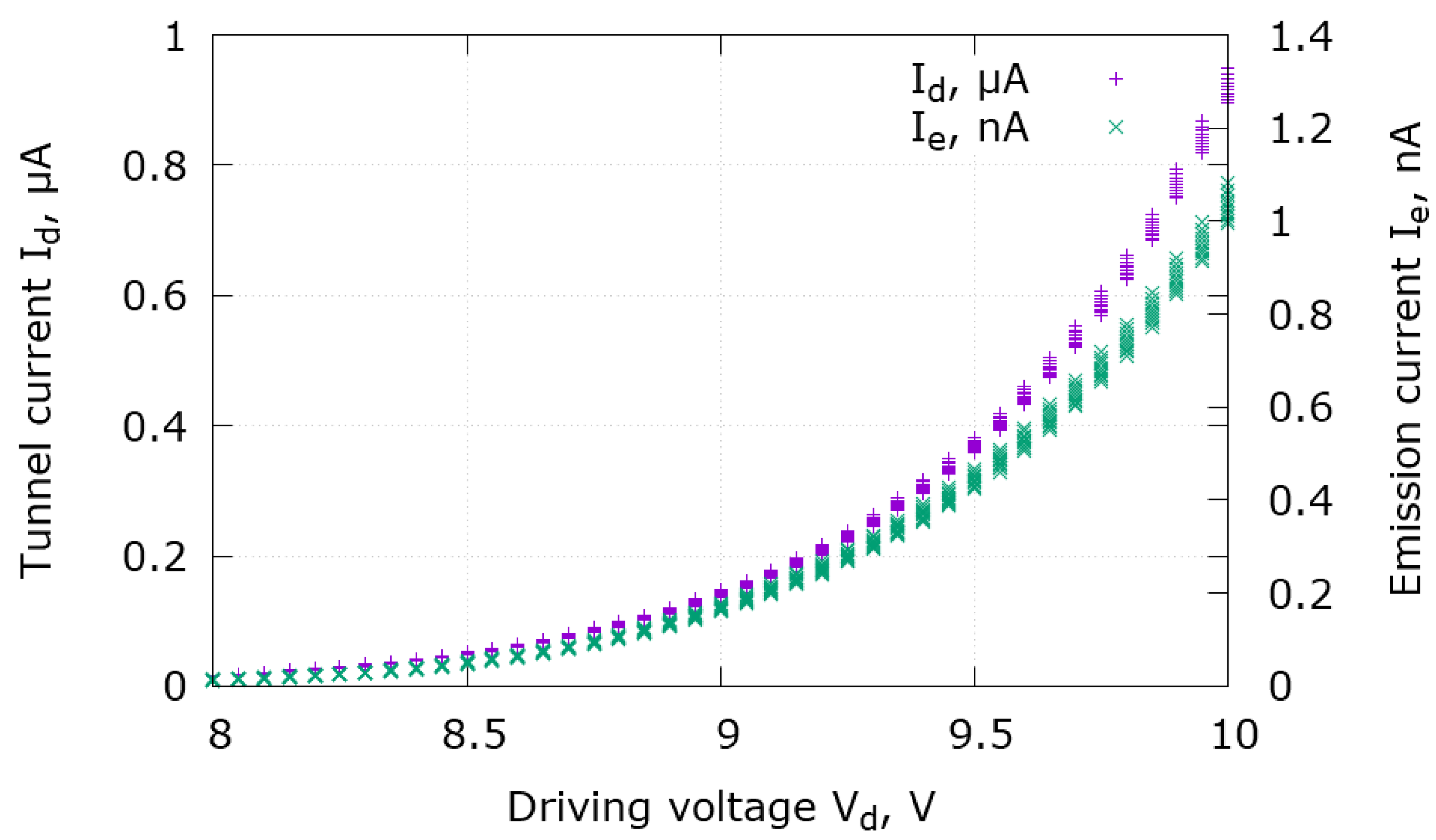
Finally, the last step is vacuum deposition of thin (about $100\mathring{A}$) layer of gold. This layer is thin enough so the electron can move through it without losing much energy, but already thick enough to provide metallic conductivity for applying voltage.

A schematic image of the sample is shown in the picture below.



4. Experimental results

The characteristic of one of the samples is shown in the figure below. This figure illustrates the occurance of the emission current following the appearance of a tunnel current.



Output ratio I_d/I_e depends on operating voltage V_d. Since the emitter has boundaries of applicability (currents $>1\mu A$ lead to fast destruction of the sample), it is crutial to make a barrier layer that satisfies the required conditions. Unfortunately, producing oxide layer is the most difficult to control and poorly reproducible stage in fabrication cycle. To lower the requirement severity for the barrier layer, we tried various interesting changes in the design and model of the device, such as additional UV radiation on the surfase or changing the geometry of electrodes. Also we are carrying out a long shot work to study the properties of the oxide layer depending on the conditions of its formation.

References

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