Study of inelastic electron tunneling in the Pt-Au tunnel junction in ultra-high vacuum STM

D.V. Lebedev[1,2], I.S. Mukhin[3,4], V.A. Shkoldin[3], A.M. Mozharov[4], A.O. Golubok[2]

[1]*Saint Petersburg State University, 199034, St. Petersburg, Russia*
denis.v.lebedev@gmail.com

[2]*Institute for Analytical Instrumentation RAS, 198095, St. Petersburg, Russia*

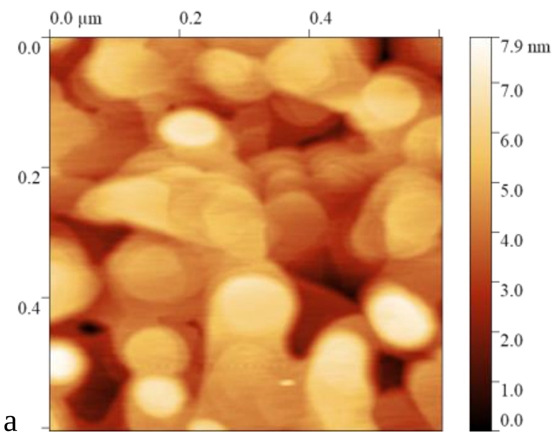
[3]*ITMO University, 197101, St. Petersburg, Russia*

[4]*St.Petersburg Academic University, 194021, St. Petersburg, Russia*

In recent years fabrication of the compact light sources operated under external applied voltage is important task in connection with development of the concept of electro-optical chips and optical computers. A promising compact light source is a tunnel junction formed between two metal surfaces located at a subnanometer distance. The phenomenon of light emission from a metal-insulator-metal (MIM) tunnel contact was first experimentally demonstrated in the work of Lambe and McCarthy [1]. Photon generation was interpreted in terms of inelastic electron tunneling and the excitation of surface plasmon waves propagating along the metal-dielectric interface. An increase in the quantum efficiency of this process can be achieved by using a tunnel gap between STP tip and metal surface in an scanning tunnel probe (STM) microscope [2, 3]. The scanning tunnel spectroscopy in a ultra-high vacuum conditions allows to investigate processes of the generation of photons under STM tip without direct collecting and detecting of photons. Analysis of the second derivative of the current – voltage characteristics (*I*–*V*) of a tunnel junction allows indirectly investigating the processes of light emission in a tunnel junction.

This work is devoted to a research of tunnel spectra of nanocontact "Pt/Ir STM tip – gold film" in ultra-high vacuum conditions that is relevant to creation of the local sources of optical radiation operated by external electric potential.

To study the Pt-Au tunnel junction, in this work atomically smooth gold surfaces were used. Preparation of crystal Au (111) films on the surface of mica was made in several stages. Freshly cleaned mica plates K_2O-Al_2O_3-SiO_2 (TipsNano Co, Estonia) were placed in a vacuum chamber of a thermal evaporation system (Boc Edwards Auto 500, United Kingdom). After that, the system was pumped to a pressure of 10^{-7} mbar. Next, the samples were heated to a temperature of 200 ºC. Then a gold film was deposited on the heated sample at a speed of (6-7) nm/min. To register the current-voltage characteristics of the Pt/Ir-Au tunnel contact, samples with gold films were loaded into an Omicron SPM Probe ultra-high vacuum system (Germany). In all STM experiments, Pt/Ir probes DPT10 (Bruker, USA) were used. Typical STM images of the sample surface is shown in Figure 1a. It should be mentioned, that the grain step height was 0.2 nm, which corresponds to the literature data for 1 layer of gold atoms [4].



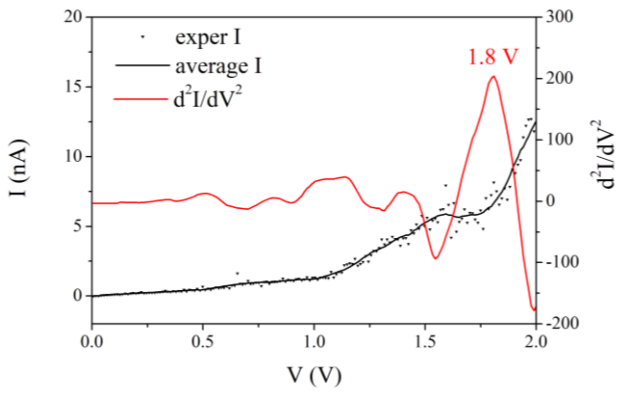


Figure 1. (a) STM image of Au (111) film on mica surface, (b) *I*–*V* curve of the Pt/Ir tip/Au film system and its second derivative.

It is well known that the process of inelastic tunneling of electrons is accompanied with the appearance of characteristic peaks on d^2I/dV^2 dependence. Figure 1b shows a typical *I–V* characteristic, as well as its second derivative, which we obtained for the Pt/Ir-Au tunnel junction. On the second derivative curve, there is an obvious peak at 1.8 V. These data indicate the presence of inelastic processes and as a result of radiation from a tunnel junction. In addition, there is an interesting area of the current-voltage curve corresponding to voltages of 1.6-1.8 V. In this range weak reduction of current at increase in voltage is observed. This fact indicates the presence of negative differential resistance, which confirms the existence of a resonant energy level in the tunneling electron transport [5]. Thus, the analisys of *I–V* curves of tunnel gap allows to study the process of inelastic electron tunneling and investigate the process of photon generation with direct optical signal collection.

This work was carried out with the support of the Russian Science Foundation (Grant 17-19-01532).

1. J. Lambe, S. McCarthy, *Physical Review Letters* **37**, 923 (1976).
2. F. Bigourdan, et al., *Physical Review Letters* **116**, 106803 (2016).
3. R. Berndt, R. James, et. al., *Physical Review Letters* **67**, 3796 (1991).
4. K. Krupski, et al., *Materials* **8**, 2935 (2015).
5. J.M. Beebe, et al., *Physical Review Letters* **97**, 026801 (2006).