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Ultra-high vacuum formation of silver films for light-emitting tunnel junctions

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Abstract. Integrated photonics requires compact electrically driven sources of optical radiation for the use in high-performance integrated circuits with optical interconnections in a chip. Light-emitting tunnel junctions represent a promising option of such nanosized light sources, even if their present quantum efficiency is insufficient for practical implementation. We propose a technique for fabrication of such junctions by ultrahigh vacuum forming of thin silver films. Testing showed a high quality and high optical response of the produced films. Such films can serve as substrates for more complicated tunnel junction structures with yet higher quantum efficiency.

Keywords: scanning tunneling microscopy, tunnel contact, emission from a tunnel contact, silver film, photonics, ultrahigh vacuum

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Формирование серебряных плёнок в ультра-высоком вакууме для светоизлучающих туннельных контактов

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Аннотация. Излучающий туннельный контакт является перспективной основой для наноразмерных электрически управляемых источников света, но обладает невысокой квантовой эффективностью для использования в фотонике. Предложен метод создания серебряных плёнок в ультра-высоком вакууме, дающих высокий оптический отклик в туннельном контакте.

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Ключевые слова: сканирующая туннельная микроскопия, туннельный контакт, излучение из туннельного контакта, серебряная плёнка, фотоника

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Introduction

The progress of computing electronics encounters various limitations, such as heat dissipation efficiency and bandwidth of electrical connections. A prospective approach to conquer these problems consists in inclusion of photonic links and photonic computing components into integrated circuits. Present photonics technologies offer many of the necessary components, though the size difference between the modern CMOS electronic components and optical sources represents a bottleneck on the way to their integration [1].

Tunnel junctions provide a promising basis for construction of compact optical sources. The visible and near infrared light emission effect supported by inelastic electron tunneling has been known for about 50 years [2]. The size of the resulting light source is defined by the size of electrical contacts. However, at present the quantum efficiency of such sources remains insufficient for their practical implementation: its typical value is as low as 10^{-6} photons per electron, and further efforts are necessary to increase this figure.

Here we report on our investigation of a method to fabricate clean Ag layers in ultrahigh vacuum (UHV) conditions, which represents an initial step to produce a light-emitting tunnel junctions.

Experiment

Sample fabrication and characterization were performed in ultrahigh vacuum conditions at the pressure not worse than $5 \cdot 10^{-9}$ mbar. All processes were conducted in a research modular platform Nanolab, which incorporates a scanning tunneling microscope (STM) Omicron VT AFM XA 50/500 (Scienta Omicron, Germany), equipment for thin film deposition, a low-energy electron diffractometer (LEED) and some other tools. The sample was fabricated on a highest quality vacuum cleaved mica (Ted Pella, USA) serving as a substrate.

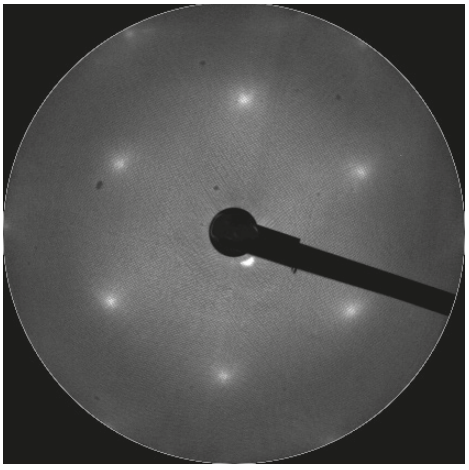

Fig. 1. Low energy electron diffraction pattern from Ag film

The mica plate was installed on a custom-made STM sample holder equipped with an optical lens. The plate was fixed by four screws; preliminary electric contact at its edges was secured with two-component silver-filled epoxy (EPO-TEK H21D). Then the top layer of mica was scratched and covered by a copper tape with an attached copper ring. After transferring the sample into the vacuum chamber, pumping and annealing, the copper tape was removed by pulling the ring with the chamber manipulator. The resulting cleaving exposed a clean mica surface. Then, a 30 nm layer of silver was deposited on the freshly cleaved mica by thermal evaporation. The silver film quality was estimated with the Low Energy Electrons Diffraction (LEED) technique: the bright peaks in the LEED image (Fig. 1) demonstrate its crystallinity.

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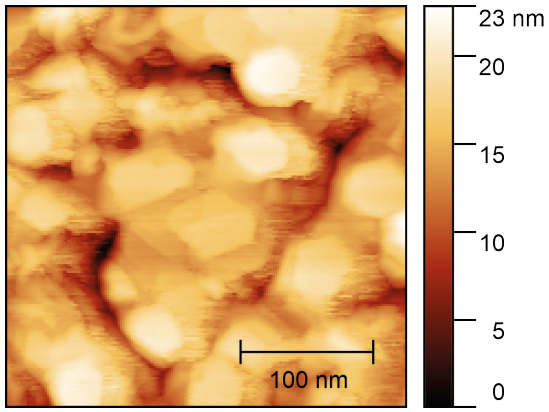

Fig 2. STM image of Ag film

Then the sample was examined by the STM. Surface topography images showed formation of large grains (Fig. 2). Studies of light emission induced by STM current were performed using the optical system described in detail in [3]: the emitted light was directed to a single photon counter ID120 (IDQuantique, Sweden) which work in visible and near infrared regions (400-900 nm). Quantum efficiency of the source based on the tunnel junction between the Ag film surface and a Pt/Ir STM tip was estimated to be about $2 \cdot 10^{-6}$ photon per electron at –2.5 V bias voltage. This estimate was calculated in the same way as the one in [4]. Notably, the current-voltage characteristics measured during the experiment showed distinct features around ±2.5 V, presumably associated with light emission from the tunnel junction assisted by optical levels [5].

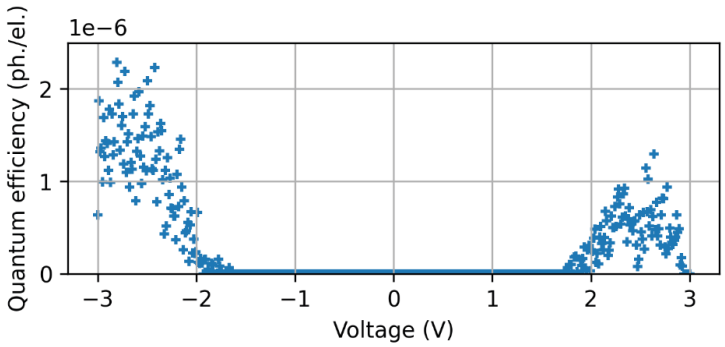

Fig. 3. Estimated quantum efficiency of tunnel junction between the silver film and Pt/Ir STM tip

Conclusion

The tested silver film has a relatively high quantum efficiency, about $2 \cdot 10^{-6}$ photon/el., as compared to the one of the previously studied gold films, which had efficiencies of about $9 \cdot 10^{-7}$ photon/el.. This developed technique and material can be used for producing more complicated tunnel junctions coupled to nanoantennas.

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