

Conference Paper

Formation of Optical Low-dimensional Structures for Photonic Elements

A. Yu. Shagurina, S. V. Kutrovskaya, O. A. Novikova, and A. V. Shagurin

Stoletov Vladimir State University, Vladimir, Russia

Abstract

In the present article, the formation of low-dimensional periodic structures with relief repeating the trajectory of movement of an AFM probe were presented. The parameters affecting their geometric dimensions: height, width, uniformity in the layer, etc., were investigated. The method of induced deposition of silver and/or gold clusters on the surface of a Bragg mirror in the presence of an external electric field was developed. The possibility of using such structures in optical elements, photoelectronic converters, optoelectronic devices of fiber optics, as well as the construction of photonic crystals (elements) based on the periodic structures is discussed.

Keywords: nanostructures, the atomic force microscope (AFM), the probe lithography

Corresponding Author:

A. Yu. Shagurina
shagurina.a@mail.ru

Received: 22 July 2018

Accepted: 9 September 2018

Published: 8 October 2018

Publishing services provided by
Knowledge E

© A. Yu. Shagurina et al. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the Breakthrough Directions of Scientific Research at MEPhI Conference Committee.

1. Introduction

Nanoparticles of noble metals, such as silver, gold, are well-known for surface plasmon resonant localization at optical frequencies [1]. Among the many notable phenomena that arise in plasmonic structures, special attention should be paid to the directional propagation of light observed at the dielectric-metal interface. Then of particular interest is the deposition of silver and gold cluster films with a controlled relief on the dielectric surface [2].

2. Materials and Methods

At present, there are various methods of creating structures on the surface of the substrate according to a pre-prepared template. Anodic oxidation lithography is a popular scientific method for creating low-dimensional structures on a surface of a sample from a previously prepared template with a nanometer-scale spatial resolution using an atomic force microscope. First of all this is due to a relatively inexpensive tool with which you can create a drawing with characteristic dimensions and efficiency, as well

OPEN ACCESS

as not requiring high-precision operations of alignment, etching, exposure, etc. In this article, a new method of electro-induced deposition of silver and/or gold clusters with a nanometer level of spatial resolution was proposed. For local formation of the relief on the surface of the dielectric, we used Bragg mirrors of GaAs/AlGaAs. The surface was cleaned by the action of ultra-sound in a bath with ethyl alcohol, at a temperature of 40°C for 5 minutes. After that, the samples were placed in a pre-prepared solution based on distilled water, alcohol in a ratio of 1:1 and a silver salt (AgNO_3). The process of saturation with silver salts took from 30 minutes to 5 hours, which subsequently influenced the height of the relief being formed. After the set time, the samples were dried and placed on a special substrate having an electrical contact, which is fixed on the stage of an atomic force microscope.

The relief was formed in air at room temperature and normal humidity (about 38%) using a scanning probe microscope on the basis of the NTEGRA Aura probe laboratory platform in the AFM contact mode. DCP 11 conducting probes with a rounding radius of 50–70 nm and silicon probes CSG 10 with a conducting Pt coating with a radius of rounding of 10 nm were used for the deposition.

3. Results and Discussion

Metal clusters were planted on the upper layer of the Bragg mirror (BM). The local relief was formed along the trajectory of the motion of the conducting needle due to local electro-induced dissociation of the metal salt in the saturated upper layer of the BM (Figure 1).

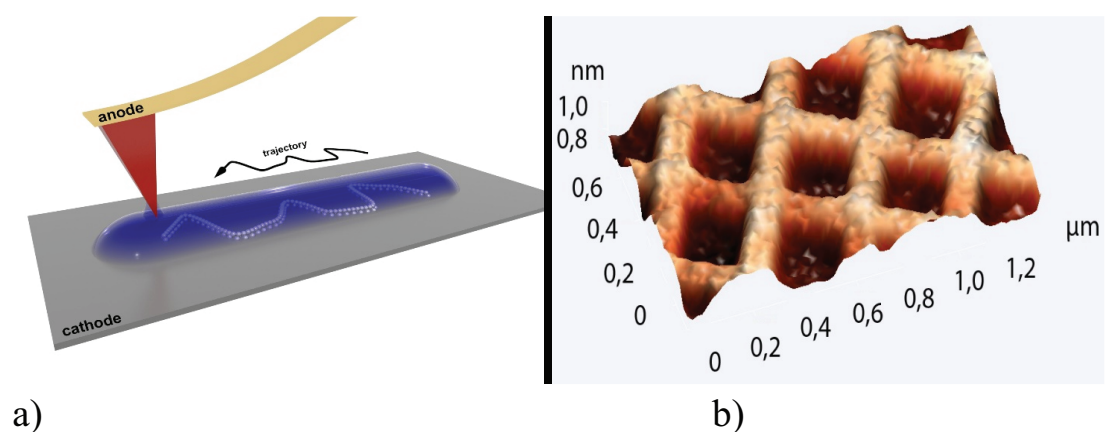


Figure 1: (a) Sketch of the process of electro-induced deposition on the basis of AFM; (b) AFM image of a sample made of silver on the surface of GaAs/AlGaAs BM.

During the deposition process, the needle of the atomic force microscope moved along a given trajectory in the contact mode at a rate of 0.16 to 1.12 Hz. A negative

potential difference from -7 to -12V was applied between the needle and the sample surface, which affected the height and width of the deposited relief. In the framework of this article, low-dimensional structures were obtained whose dimensions are well controlled by the bias voltage supplied between the needle and the sample surface. The average thickness of such structures can vary in the range from 80 to 150 nm, which is determined by the diameter of the constriction of the water meniscus formed between the tip of the needle and the substrate; in height from 0.7 to 4 nm, the increase in relief height is achieved by repeatedly passing the probe along the same trajectory. There is a linear dependence of the thickness on the number of repetitions. Figure 2 shows the result of 10 repetitions, which is visible by scanning electron microscope.

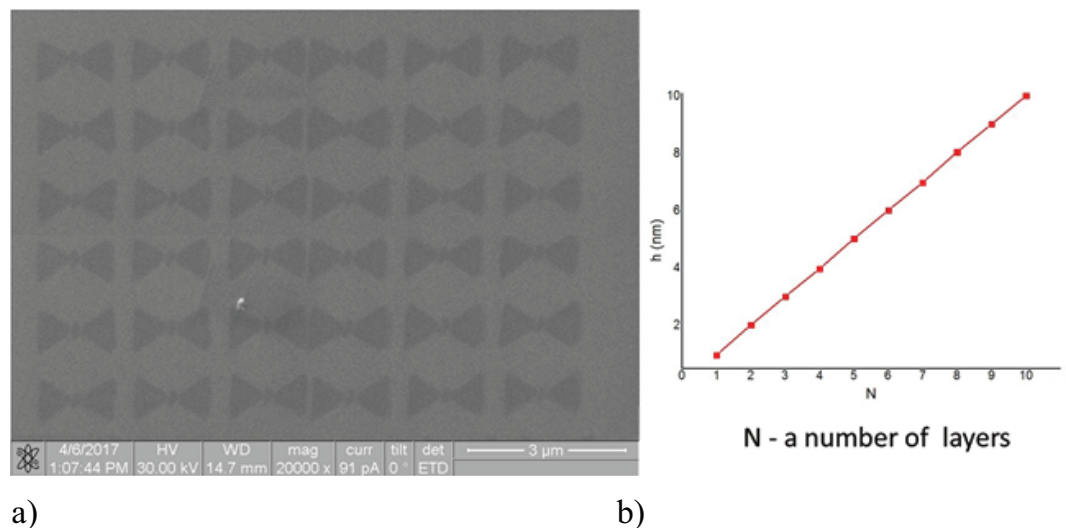


Figure 2: (a) SEM image of the deposited structures; (b) Dependence of the height of the structure on the number of repetitions.

4. Conclusion

The results obtained in this article will allow us to create a significant reserve in the field of photonics. Further development of the project will allow creating new hybrid devices, which will allow creating an element base of a new generation (high-speed information transfer, low-power lasers and amplifiers, optical computers and systems for recording, processing and displaying information by optical methods).

In this article, a new method of electro-induced cluster deposition was proposed using the AFM base in the contact mode. The developed method has proved to be a stable and simple tool for lithography, for which special conditions such as high humidity, a substrate with a thin layer of well oxidized metal are not needed. It is

also shown that a change in the concentration of brine and the saturation time of the substrate leads to a change in the height and width of the resulting structures. The change in other parameters, such as humidity and temperature, did not lead to a change in the deposited relief, which is explained by the fact that a metallic track is formed on the surface, and not an oxide track.

Funding

The authors collectively express their gratitude for the results obtained within the framework of the RFBR grant No. 16-42-330461 p_a.

References

- [1] Antipov, A., Arakelyan S., Vartanyan, T., et al. (2015). Optical properties of nanostructured gold–silver films formed by precipitation of small colloid drops. *Optics and Spectroscopy*, vol. 119, pp. 119–123.
- [2] Arakelyan, S., Veiko, V., Kutrovskaya, S., et al. (2016). Reliable and well-controlled synthesis of noble metal nanoparticles by continuous wave laser ablation in different liquids for deposition of thin films with variable optical properties. *Journal of Nanoparticle Research*, vol. 18, pp. 154–158.