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The obtaining of regular metal and dielectric microstructures based on irradiation–modified polymer films

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Based on regular porous polymeric membranes, the synthesis of metal and dielectric spearhead structures with given morphological characteristics was carried out. Copper structures with the $\sim 1\,\mu$m height and dielectric spearhead microstructures made from iodic acid with the $12\,\mu$m height and $1\,\mu$m diameter were obtained. The possibility is discussed of using such optical elements to solve the problems of increasing the efficiency of IR radiation detection, signal amplification and conversion to visible and near-infrared ranges.

Keywords: regular membranes, spearhead structures, copper, iodic acid, radiation transformations.

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Regular microstructures are at present used as components of various microelectronic devices. Studies aimed at increasing the efficiency of detecting laser IR-radiation are being performed [1]. The relevant way for this is to use arrays of ordered metal and dielectric spearhead microstructures. Choosing for them different materials and geometry types, one can vary the radiation penetration depth and define specific features of interaction between the structures and radiation (up to changing the respective wavelength). Theoretical assessment of the local field enhancement factor shows that the requirements for geometry of the spearhead structures and for structures made from optically active dielectric crystals are different. In the first case (Fig. 1, *a*) , the greatest effect may be expected when the spearheads are about $0.5-1\,\mu$m high; in the other case (Fig. 1, *b*), desirable are microcrystals about $10\,\mu$m in height and a few micrometers in diameter.

Notice that one of the main advantages of the structures under consideration is their highly prominent periodic character. This makes them more efficient than structures based on chaotically arranged microparticles which are used to generate the harmonics [2]. In this work we consider a method for obtaining ordered arrays of metal spearheads and dielectric optically active microcrystals on polymer films with regular micropores formed by using a source of synchrotron radiation.

The synthesis of regular metal surface spearhead structures was performed by using porous polymer films. The pore diameter and depth were defined by the parameters of the polymer irradiation through a periodic-relief titanium matrix [3]. In this study, polyethylene-terephtalate (PET) polymer films $10\,\mu$m thick were used. Such an irradiation of the polymer followed by etching enabled obtaining a quite perfect porous structure with pore diameters of $\sim 1\,\mu$m and depths ranging from fractions of micrometer to the polymer thickness of $10\,\mu$m.

The procedure of the regular metal structure formation included several stages. A thin silver layer about 50 nm thick was deposited on the surface of the initial polymer mask in order to create and retain the current-conductance characteristics, which was further used in depositing copper. Using the technique of the potentiostatic electrochemical deposition, metal spearhead microstructures (copper in this case) were applied on the thin silver underlayer at room temperature during 30 min [4]. The deposition was performed so that copper fully filled the pores, and a metal base $10-20\,\mu$m thick was formed. The obtained metal microstructures were $\sim 1\,\mu$m thick at the repeatability period of about units of micrometers (Fig. 2, *a*).

The PET polymer films were also used as a base for forming continuous microstructure HIO_3 [5] (Fig. 2, *b*). This was done by submerging the porous film into an oversaturated to 11% solution with subsequent drying of the film. In this case, the radiation dose was fit so that the polymer film was etched through.

To obtain extended microcrystals of iodic acid, the method of forced flow of oversaturated solution through the open-end membrane pores was used [5]. Spearhead microstructures with the height of about $12\,\mu$m and cross sizes matching the pore diameter of $1\,\mu$m were obtained. In each pore, several spearhead structures $0.3-0.5\,\mu$m in diameter were formed.

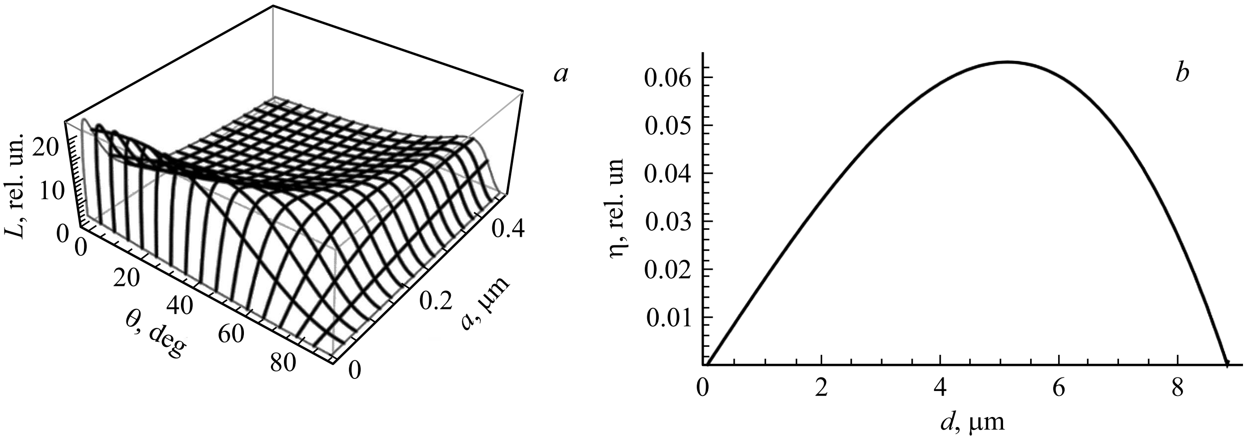

Figure 1. *a* — the local field enhancement factor under the plasmon resonance excitation on the periodic metal surface structure versus incidence angle θ and structure profile height *a*; *b* — relative efficiency of the signal generation at the second harmonic frequency η in dielectric microcrystals versus their diameter *d*.

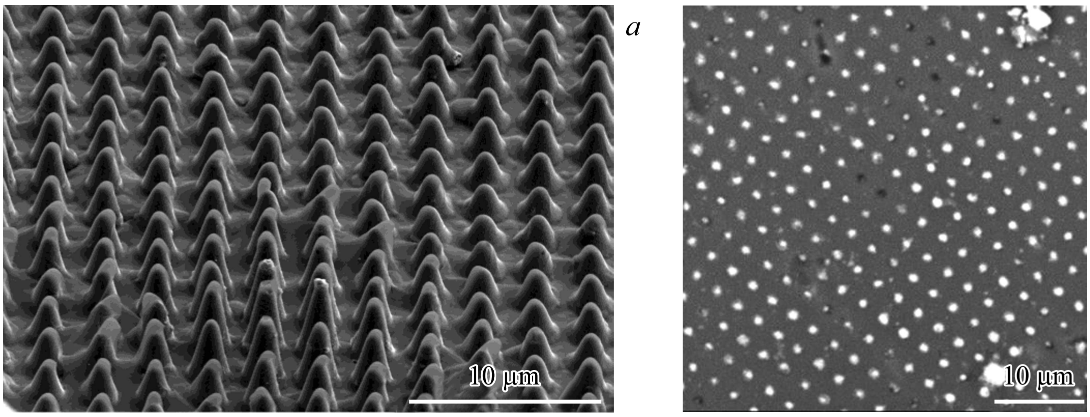

Figure 2. Near-surface microstructures. *a* — copper, raster electron microscope (REM) FEI Scios; *b* — HIO_3, scanning electron microscope Phenom PRO-X.

Fig. 3 presents REM images of the surface (a) and cross-section (b) of the regular membrane with the grown HIO_3 crystals; the cross section was made by a focused ion beam.

The energy dispersion analysis of the samples under study has demonstrated that they contain oxygen and iodine.

Periodicity of the synthesized structures was controlled via optical diffraction. The optical diagnostics revealed a high-strengh order of the obtained structures; the experimentally observed reflection spectral features are relevant to the excitation of surface plasmon polaritons.

Based on the regular porous membranes, metal spearhead structures $\sim 1\,\mu$m high were synthesized. Metal spearhead structures enable non-resonance electric field enhancement, as well as resonance enhancement in case the primary radiation frequency belongs to the range of plasmon resonance of the metal spearhead structure [1].

Spearhead microstructures HIO_3 $\sim 12\,\mu$m in height and $\sim 1\,\mu$m in pore diameter were obtained. For dielectrics, the surface microstructure breaks the symmetry of a homogeneous material properties and thus increases the efficiency of the radiation generation at the second harmonic frequency during reflection from the surface [6]. The calculations show that in the case of diffraction of the polarized radiation on these structures created in the PET film cylindrical pores, the squared electric field module increases on the cylinder surface by about 9 times. At the edge of the cylinder there takes place a strong spatial dispersion that makes higher the efficiency of the radiation−to−signal transformation at the second harmonic frequency.

Thus, the microstructures under study are promising as optical elements to be used in solving the tasks of increasing the efficiency of the IR radiation detection, signal amplification and conversion to the visible and near IR ranges. Notice that the issue of creating structures with the highly accurately maintained period (with the spread below 1%) is quite topical and is discussed in terms of developing novel optical elements and laser radiation sources [7–9].

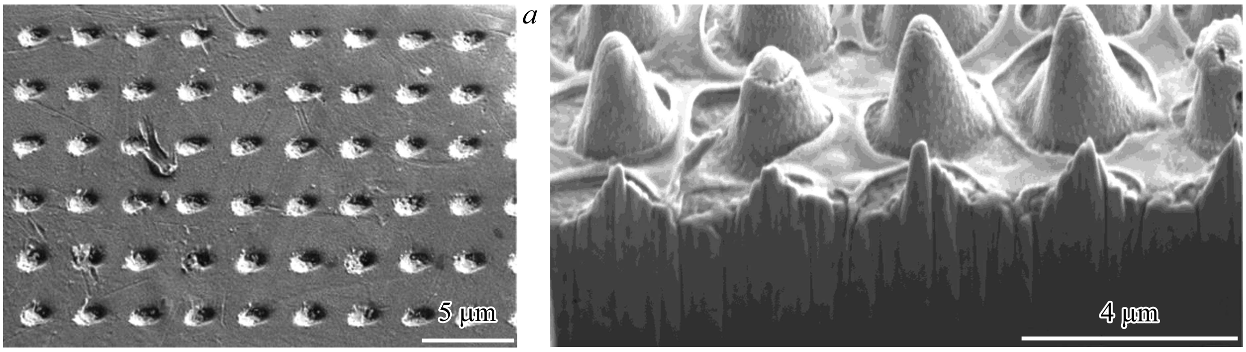

Figure 3. REM images of the surface (*a*) and cross-section (*b*) of the regular membrane with the grown HIO_3 crystals.

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Conflict of interests

The authors declare that they have no conflict of interests.

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