NON-LITHOGRAPHIC NANOTECHNOLOGIES FOR 2D AND 3D NANOFABRICATION

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Abstract. In this paper we present a review of technological approaches for 2D and 3D nanofabrication of semiconductor compounds by using radiation treatment and electrochemistry. Novel spatial nanoarchitectures based on III-V and II-VI compounds as well as two-dimensional metallo-dielectric structures in different geometries are demonstrated. A breakthrough in the design and fabrication of ultrathin membranes of non-layered wide-band-gap semiconductor compounds is presented. Possible electronic and photonic applications of the elaborated nanostructures are considered.

Keywords: Nanofabrication, electrochemical etching, direct writing, nanowires, nanotubes, ultrathin membrane, III-V compounds, II-VI compounds

Over the last years, we elaborated technological approaches for 2D and quasi-3D nanostructuring of III-V and II-VI semiconductor compounds using anodic etching under controlled conditions. The nanostructured matrices served as conductive templates for the development of arrays of metal nanotubes and nanowires by electroplating. As a result technological routes have been elaborated for the fabrication of two-dimensional metallo-semiconductor quasi-periodic structures for photonic applications. In particular, Platinum-semiconductor 2D quasi-periodic structures have been successfully elaborated on InP (E_g = 1.3 eV), GaP (E_g = 2.3 eV) and ZnSe (E_g = 2.7 eV) single crystalline substrates [1,2].

In our attempt to broaden the areas of applications of electrochemistry when combined with preliminary radiation treatment, some years ago we proposed the approach of surface charge lithography (SCL) as a tool for maskless microstructuring and nanostructuring of GaN epilayers [3,4]. The approach is based on treatment of the semiconductor compound epilayer by a low-dose low-energy ion beam with subsequent photoelectrochemical (PEC) etching of the sample. The ion-beam induced lattice defects trap electrons leading to the appearance of a surplus of negative charge in the near-surface region of the GaN sample. It is the negative charge that protects the ion-beam treated areas against PEC etching. So, using the ion-beam-induced negative charge as a shield against PEC etching, we demonstrated unique possibilities for GaN nanostructuring, including fabrication of ultra-thin GaN membranes suspended over networks of nanocolumns/nanowhiskers related to threading dislocations [5-7].

The goal of this work is to explore new technological possibilities for 2D and 3D nanostructuring of semiconductor materials for electronic and photonic applications. Some of the most important technological and applicative issues to be considered are mentioned below.

In collaboration with the University of Oxford, we found that the surface charge density in nanoperforated InP membranes can be altered by photoexcitation [8]. The photoinduced modification of the surface properties in porous semiconductors is useful in material processing for various applications. In particular, important efforts are focused on the development of THz emitters based on InP honeycombs. Recently [9] we demonstrated that irradiating InP honeycombs with heavy noble-gas ions (85-MeV Kr and 130-MeV Xe ions) enhances terahertz emission excited by femtosecond IR-laser pulses (790 nm). Systematic investigation of the dependence of the generated terahertz electric field on excitation pump power, in-plane magnetic field, and azimuthal angle are indicative of optical rectification as underlying physical mechanism.

As a result of technological explorations, we found that photoelectrochemical etching of GaN combined with preliminary low-dose low-energy focused-ion-beam treatment of the sample surface provide conditions for both 2D and 3D micro-nanostructuring of this important electronic material. In case of 2D nanostructuring, it is possible to fabricate in a controlled fashion arrays of nanowires and nanowalls for sensor and photonic applications. By controlling the fluence of the ion treatment as a function of x-y coordinates, we reached conditions for the fabrication of both ultra-thin membranes and supporting nanocolumns in the same technological route [10]. Note that PEC etching in-depth is possible due to high transparency of the membrane to ultraviolet light. The developed novel maskless nanotechnology has been highlighted recently by the prestigious site NanoTechWeb.org in Great Britain, see http://nanotechweb.org/cws/article/tech/49261.

Possible applications of the developed non-lithographic technologies and nanomaterials will be considered. Besides, the results of realization of FP7 project MOLD-ERA will be highlighted.

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