Nanocomposites based on porous silicon: from idea to implementation

V. Bondarenko
Belarusian State University of Informatics and Radioelectronics, Belarus

1. Introduction

Silicon technology has become so powerful that it pervades all spheres of our life. That is why namely silicon is the most desirable semiconductor to be a host for integration of radically new solid-state microsystems including but not limited to electronic, magnetic and optical devices. At the same time, it is common knowledge that the monocrystalline silicon (*c*-Si) demonstrates a negligibly weak photoluminescence (PL) and is non-ferromagnetic at all. For the last 50 years, many different approaches have been studied to impart ferromagnetic properties to the *c*-Si or improve its PL. However, state-of-the-art silicon technology is still not able to meet the industrial requirement of successful integration of magnetic, electronic devices and light emitting diodes (LED) in one silicon chip.

Silicon nanostructuring followed by an incorporation of other ("guest") materials is a promising alternative to modification of the *c*-Si itself. This way opens an opportunity to push the boundaries of traditional silicon technology, because the resulting nanocomposites will show the properties that are not typical for the *c*-Si and can be easily tuned by the nature of the incorporating materials.

This paper presents a review of a long-term activity of our research group aimed at finding a simple and efficient approach to synthesize nanocomposites in silicon with outstanding optical and magnetic properties. To achieve this challenging objective we used a general idea of the formation of ordered arrays of pores in silicon (*por*-Si) and their further filling with different materials to provide target properties [1]. Fabrication procedures, versatile characterization of the obtained nanocomposites and their ongoing and possible applications are discussed in this review.

2. Experimental

The *por*-Si samples of principally different morphologies were formed by electrochemical and metal-assisted chemical etching of the *c*-Si. Electrochemical and electroless methods were used to deposit rare-earth elements (REEs), magnetic and coinage metals and ZnO in the *por*-Si. Morphology of the samples was studied by scanning electron microscopy, energy-dispersive spectroscopy and X-ray diffractometry. Magnetic characterization was performed by measuring the magnetization at the temperatures from 77 to 700 K by static ponderomotive method. PL spectra were recorded at the room temperature using a complex of a monochromator-spectrograph with CCD camera. Plasmonic properties were studied by simulation of electric field, recording reflectance spectra and surface enhanced Raman spectroscopy of analytes adsorbed on the surface of nanocomposites.

3. Results and Discussion

Different combinations of the pores' geometries and deposition regimes of the "guest" materials allowed managing the nanocomposite type. We fabricated arrays of "guest" nanoparticles (NPs) laying on the *por*-Si external surface and pore-shaped nanowires (NWs) incorporated in the pores.

The nanocomposites based on magnetic metals' NPs and NWs in the *por*-Si layer of a 10-μm thickness were shown to demonstrate magnetic anisotropy, giant magnetoresistance and coherent spin waves. These properties are important magnetic recording, magneto-optics and sensing.

Deposition of the REEs (Er, Tb, Eu and Gd) in the *por*-Si resulted in fabrication of hydroxides of these elements in the pore channels. An oxidation step followed by annealing at a high temperature in inert atmosphere led to creation of the nanocomposites demonstrating an intensive PL with sharp emission peaks of the REEs.

In case of ZnO the *por*-Si thickness significantly affected the oxide deposition. If it is about 1 μm, the ZnO will grow on the surface of the porous layer, while the 10 μm thickness will result in the ZnO crystallization in the pore channels. Remarkably, the last nanocomposite was found to show slight magnetic properties and a strong visible PL that are of a great interest for magneto-optics, micro-LED and sensor applications.

The plasmonic nanocomposites were shown to extremely enhance absorption of visible and IR light and PL efficiency of REEs' NPs adsorbed on their surface.

4. Conclusion

We were able to induce ferromagnetic properties in the *por*-Si by introduction of Ni, Co or Fe into its pores. The PL was enhanced in the same way through the introduction of REEs and ZnO. In addition, we found that deposition of coinage metals on/in the *por*-Si leads to formation of nanocomposites with strong plasmonic properties.

5. Acknowledgements

The author is grateful to the members of the laboratory "Materials and structures of nanoelectronics" whose dedicated work made this complex research possible.

6. References

[1] E. Chubenko, S. Redko, A. Dolgiy, H. Bandarenka, V. Bondarenko, "Porous Silicon as Host and Template Material for Fabricating Composites and Hybrid Materials. In: Porous Silicon. From Formation to Application. Editor: G. Korotchenkov. CRC Press Taylor & Francis Group, pp.141-162, 2016.