Nanoporous GaN – a new platform for realization of quantum structures

Gallium nitride (GaN) is a material of truly unique properties. One of its particular features is the capability for effective conversion of electric energy to light – in contrast to silicon (Si). Nowadays, the energy saving LEDs are based on GaN. Nevertheless, despite that Si-based structures do not emit light, an interesting discovery was made simultaneously but independent by Lehmann and Canham at the beginning of the nineties of the last century. They observed that the emission of light from Si can be considerably improved if Si is made porous. "Porous" in this context means that billions of nanometer-size holes, are made in a normal single crystalline Si substrate. Thus, a device based on porous Si will emit light, whereas one based on a normal single crystalline Si substrate will not. Maybe the efficiency is not as spectacular as the one obtained from GaN, but it was a real discovery! Since then, both porous semiconductors and the technique that allows to form pores, became a subject of intensive studies. Of course, these scientists did not have dwarfs that would dig these holes in silicon with nano-blades. They used the well-known electrochemical etching technique, immersing Si in hydrofluoric acid. In order to dissolve the crystal in a way to form pores, a positive bias is applied. It forces the positive carriers to the interface semiconductor/electrolyte. A positive charge, called a hole, is nothing else than a missing electron. When it happens to be at the surface, it helps to break the atomic bonds and the material can be easily dissolved. For the specific conditions of bias, carrier concentration the porous structure is obtained.

The project goal is to investigate the mechanism of GaN electrochemical etching to obtain nanometer-size pores. In the next stage, we will use nanoporous GaN as a platform for implementing interesting quantum structures. The aim of the project is to thoroughly investigate the conditions in which a porous structure can be obtained in p-type and n-type material, i.e. in which there are positive (holes) and negative (electrons) carriers. Mg and Ge dopant atoms will be introduced during crystal growth by molecular beam epitaxy (MBE). It is particularly interesting for us to obtain GaN with pores of sizes <10 nm in diameter, because then it will be possible to study extremely interesting effects in the field of quantum physics. To achieve this goal, we need to etch highly doped GaN:Si at low voltages, as shown by our initial research. We also want to confirm this for GaN doped with Ge and study the etching mechanism in the case of GaN doped with Mg. Such materials have not previously been electrochemically etched. This is because commonly used technology for the growth of nitride structures (MOVPE) has problems in achieving high doping levels without structural deterioration. In addition, we will examine what will happen when we intentionally introduce defects into the material (using ion implantation) and change its conductivity. Our initial research shows that only if we have holes in the material are we able to "block" etching by implantation. In the case where we etch n-type GaN after implantation, etching occurs even more effectively than for material without defects. It is very interesting and worth in-depth research.

In the second part of the project, nanoporous GaN will be used as a platform for the implementation of quantum structures. Physicists are excited to study the coupling of light with vibrations of the crystal lattice, which in such a changed material as nanoporous GaN will be extremely interesting. Even more so if the pores are quantum size, i.e. <5-10 nm. A completely new idea that will be implemented are nanoporous quantum wells, where the presence of pores will affect the intensity of light from such wells, and also change the wavelength, i.e. color. We expect to increase the wavelength because the presence of pores will reduce stress state. In the case of GaN-based emitters, the efficient light emitters in longer wavelengths, i.e. in the green, yellow and red color range are strongly desired. We believe that our research will open new perspectives in this area and help to solve the challenges. Another element of the project will be a completely new idea in which we would like to use the unique feature of a GaN crystal, namely the fact that it is a polar crystal with a strong electric field in the structure. An electric charge and so-called two-dimensional hole gas appear on the surface of layers with different chemical compositions. We want to investigate whether we can "cut" the crystals with atomic precision by using holes in this area for electrochemical etching.