Last year's Nobel Prize in Physics was awarded for the development of efficient visible light sources in the form of light-emitting diodes (LEDs). These diodes use as material emitting light a family of nitride semiconductor. Such as gallium nitride, indium nitride and aluminum nitride (GaN, InN, AlN). In real LEDs structures also ternary nitride alloys are used, including InxGa1-xN and AlyGa1-yN. The first form quantum wells emitter, the base element enabling efficient generation of visible light. The x and y denote ratio of cation content of In and Al to Ga, respectively and determine the energy of the emitted light i.e., the wavelength of the radiation. Colloquially it speaks of the light colors. Blue light corresponds to a wavelength of about 450 nm.

From a physical point of view, the energy of the LED emission corresponds to the magnitude of the so-called energy gap of the used semiconductor. It is a region of energies forbidden for electrons. Excitation of electrons through the band gap, requires an external light source or applying (through electrical contacts) external voltage inducing current flow through the structure of the LEDs. Electrons returning to the initial states, release an appropriate energy and a beam of light in form of photons is emitted. The use of LEDs for lighting is of great importance in the context of the multibillion-dollar savings in reducing the cost of electricity used for lighting with traditional emitters, such as light bulbs. It should be emphasized that this economic aspect has been strongly stressed in support of the granting of the Nobel Prize in 2014.

Achieving efficient LEDs were preceded by two decades of physicists and engineers research carried out in laboratories around the world, including in the laboratories of our Institute. Still many aspects of the physical mechanisms responsible for this spectacular technological success requires a deeper understanding what causes difficulties in further significant improvement of nitride LED performance. This applies to both structural parameters of such devices as well as to still unsatisfactory efficiency in the transformation of energy supplied in the form of an electric current into light. The current Project deals with both these issues.

Commercially available nitride LEDs operating in the visible region are produced in the so-called “planar architecture”. It consist the sequential deposition of layers with different properties on the substrate imposing parameters of the crystal structure of the deposited layer. This is done through a process called epitaxy. The closer the distance between the atoms of the layer (and their mutual arrangement - symmetry) to the appropriate quantities characterizing the substrate, the better layer structure and thus the whole light-emitting diode can be obtained. As it is well known, Polish specialty in the field of nitride semiconductors it is the ability to produce a perfect crystal GaN - ideal material for substrates. Due to their high cost currently cheaper "foreign" substrates are used (in industrial scale), such as sapphire, silicon and less frequently silicon carbide. Suitable technological procedures allow to adopt such substrates to growth processes but the price for such treatments is a significant number of defects that reduce the efficiency of light emission achievable by nitride LEDs. The use of Polish GaN substrates in this project is its important asset.

According to current trends of microelectronics and microphotonics, entering into "NANO" areas, a very important aspect of the research is the miniaturization of devices. In addition to material savings (and increase operational efficiency), there are new physical effects associated with reducing the size of device structures. This also applies to the miniaturization of the LEDs. The current development consisted mainly of nanostructualization of planar devices with macroscopic dimensions. The main objective was to improve their effectiveness in applications related to lighting. In parallel, however, sustained research aimed at application associated with nanolitography, the generation of nanoscale patterns (direct writing), resonant and selective energy transfer in the form of light to materials containing large molecules and quantum dots. These latter areas relate mainly to the bio-scinces.

In order to miniaturize LEDs in multi-emitter systems (up to sub-micron size) two approaches are used: more developed technique "bottom-up" and used much less frequently: "top-down". Both lead to construction and fabrication of column emitter arrays with micron and submicron sizes, containing all the elements of macroscopic LEDs and their electric power supply. The first approach involves the use of selective growth of micro/nano-columns on previously prepared substrate. For example: through holes in the metal masks. The most important part of the second approach is reactive ion etching technique, that combines the action of the chemical reactive gas (eg. Cl), and physical plasma action. It requires the application of appropriate masks allowing for removal material of the macroscopic LED from area between columns protected by appropriate masks. In the current Project we will deal with the columnar miniature LEDs with dimensions between 0.5-2 μm, produced by double etching. The second process is a "wet" chemical etching of columns applied after the above-described plasma etching. "Wet" etching allows to obtain both a perfect columns side walls and to reduce their diameters. Mirror-like surfaces of the columns side wall (with facets) are important for the light guiding abilities of these emitters.

In order to obtain micro- and nano-structured matrix LEDs with etching methods, preparation of suitable masks becomes a critical issue. We will use optical photolithography methods and electronolitography. First to form mask uses the laser beam, the second - beam of electrons.

We will also attempt the use of nano-masking techniques using etch-resistant micro / nano particles, such as, for example silica small spheres. Besides of preparation of columnar arrays of miniature LEDs we also plan to produce separated, single column emitters. They improve the optical properties of such nano-devices, in particular the increase of emission efficiency. Moreover, such single emitter enables achieving a very narrow electroluminescence line, created by the so-called excitons. The latter situation allows to use LEDs to emit single photons. We will test such features of the prepared sigle nano LEDs.

In the proposed project we can use tested in our Institute, planar methods for epitaxial growth of high-performance quantum well structures deposited on defect free GaN substrates. Successful use of the "top-down" approach (with additional wet etching) for miniaturization of these structures, would create a chance for our Institute to study different and fascinating physical phenomena appearing in sub-micron nitride structures, including column LEDs.