The Project objectives and motivation. The main objective of this Project is to explore and develop a new generation of micro-LED structures capable of emitting in the long-wavelength region (above 570 nm) with the strong potential for achieving the red part of the visible spectrum.

Micro-LEDs (µLEDs) are expected to combine high brightness, efficiency, fast switching, and small size. They are ideal for biomedical, sensing, and display applications. Red µLEDs are gaining a lot of attention due to their potential applications in optogenetics, neural interfaces, and phototherapies thanks to deep tissue penetration [1,2]. Red µLEDs also serve as precise light sources in sensors and lab-on-chip systems and are explored for high-speed VLC and Li-Fi [3] or RGB displays [4]. Red InGaN µLEDs face several key challenges. Achieving red emission requires high indium content, which induces significant strain and leads to crystal defects that reduce material quality and efficiency. This strain relaxation causes d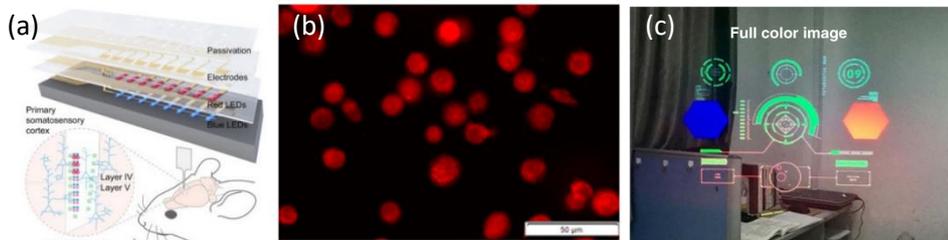islocations that decrease carrier lifetime and quantum efficiency, resulting in increased non-radiative recombination and lower brightness. Finally, high-indium structures tend to have reduced thermal and electrical stability, which affects the long-term performance of the

Figure 3. Application examples of red LEDs: (a) precise control of neuronal activity[1], (b) cancer cells detection [2], (c) AR display [4].

devices. To address these challenges and promote higher indium incorporation, significant research has focused on reducing compressive strain in GaN based substrates such as: partially relaxed InGaN templates, GaN films grown on two-dimensional (2D) materials and GaN-on-silicon platforms. However, the most promising approach is the use of porous pseudo-substrates, which enable elastic relaxation. This relaxation not only reduces strain but also leads to fewer defects that typically decrease emission efficiency.

In order to solve these problems, we propose an innovative approach by using InGaN/InGaN superlattices (SLs) with different geometries in active region, grown on precisely engineered porous pseudo-substrates. By carefully selecting the widths of quantum wells (QWs) and quantum barriers (QBs), together with the design of customized porous substrates, we aim to enable higher indium incorporation, reduce internal strain and achieve highly efficient optoelectronic devices. The active region will consists of a set of $In_xGa_{1-x}N/In_yGa_{1-y}N$ SLs with various geometries and with extremely narrow QWs of 0.5-2 nm, variable indium content x>0.16 and with a quantum barriers (QBs) width of 0.75-5 nm and y<0.1. To reduce strain we propose the use of porous pseudo-substrates which provides elastic relaxation with higher structural quality comparing to other popular methods.
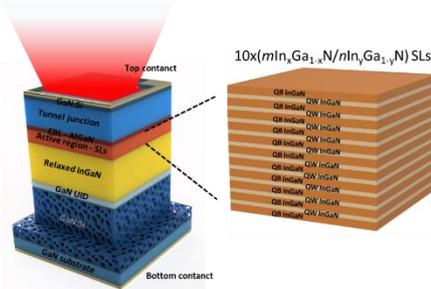

Figure 2. Scheme of µLED structures with active region consisting of SL with 10 periods of InGaN/InGaN QWs.

The superlattices proposed as the active region of µLEDs are composed of ultra-thin quantum wells (QWs) and quantum barriers (QBs) with only a few atomic layers thick. Due to the close proximity of these layers, the wave functions of QWs and QBs strongly interact, enabling precise tuning of optical properties. A key advantage of using superlattices is the ability to adjust the emission wavelength by varying the thickness of the QWs and/or QBs. Moreover, carrier tunneling through thin barriers allows for more uniform band filling compared to conventional quantum well structures, potentially enhancing emission efficiency. By combining the exceptional properties of SLs with the use of porous pseudo-substrates, this approach opens up new opportunities for the development of high-efficiency red emitting µLEDs.

Impact of the project on the development of the field.
Introducing high-efficiency, long wavelength µLEDs will be a breakthrough for both industry and science. It will enable full-color displays with monolithic RGB integration, boosting AR/VR, wearables, and automotive tech by outperforming OLED and LCD in brightness, efficiency and lifespan. In biomedicine, it will enhance deep-tissue imaging, optogenetics and implantable devices. Scientifically, efficient red InGaN emission will advance strain control, bandgap engineering, and quantum design, improving our understanding of carrier dynamics. The proposed short-period superlattice aims to boost emission and demonstrate a strong proof of concept, pushing forward light-emitting technologies and semiconductor physics.

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