Simulation of tunnel junctions for use in ultraviolet-emitting vertical-cavity surface-emitting lasers

Background

Realizing semiconductor lasers with an emission wavelength in the ultraviolet (UV) wavelength regime is not only curiosity driven research exploring the limits of technology, but also research with a clear goal of developing compact, power efficient light sources for sterilization applications and medical diagnosis and treatment. Until recently, there were no demonstrations of UVB- (280-320 nm) or UVC-emitting (<280 nm) vertical-cavity surface-emitting lasers (VCSELs), but last year our research group at the Photonics Laboratory at MC2 demonstrated the world's first optically pumped UVB-emitting VCSEL. However, optically pumped VCSELs are just the first step, and we aspire to realize electrically injected UV VCSELs. To achieve this, there are several challenges that needs to be addressed. Two of the main issues are the high electrical contact resistance and poor current spreading of the p-doped semiconductor material (AlGaN) that is needed in the lasers. Mg atoms are used as p-dopants in AlGaN, but the high ionization energy required to ionize the dopants results in very few of them contributing with holes at room temperature and thus a very low electrical conductivity of p-doped material. Therefore, the electrical conductivity of n- and p-doped AlGaN can differ by orders of magnitude and make current spreading on the p-doped side very challenging.

A potential way to circumvent the problem with highly resistive p-AlGaN is to instead use a tunnel junction (TJ), which essentially is a heavily doped reverse biased pn-junction, see Fig. 1. In a TJ, electrons from the valence band of the p-doped layer can tunnel through the potential formed at the interface between the p- and n-doped layers and end up in the conduction band of the n-doped layer, see Fig. 2. In this way, holes can be injected into the active region of the VCSEL while the current spreading on the p-side reducing the effect of poorly conducting p-doped AlGaN.

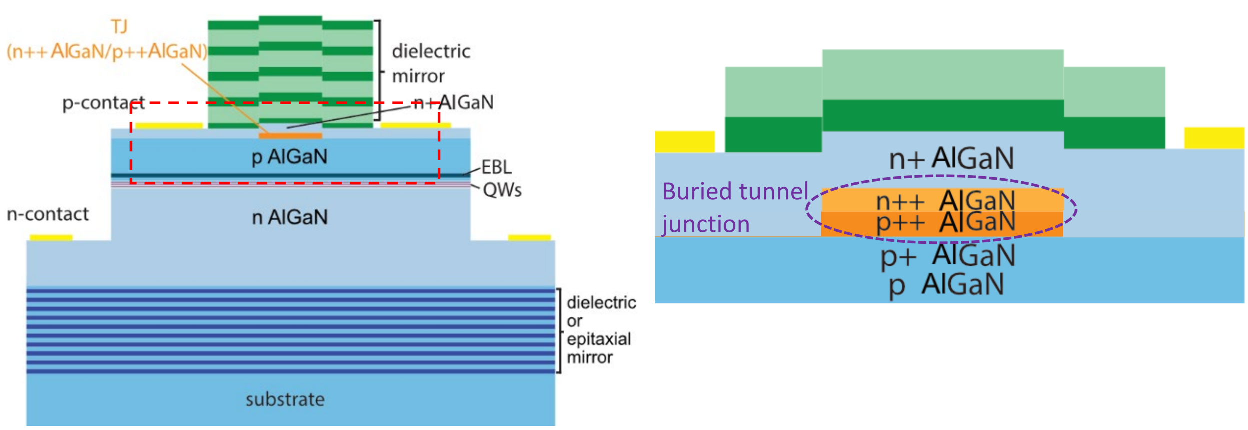

Figure 1. (left) Schematic view of a TJ VCSEL and (right) a zoomed-in view of the TJ.

Thesis goals

The goals of this thesis are to simulate the current-voltage characteristics of TJs and evaluate different designs for example in terms of differential TJ resistance as illustrated in Fig. 3 for a TJ for a UV light-emitting diode. One way to do this would be to develop a software that solves the Poisson-Schrödinger equation, e.g. using Matlab. A literature study will have to be performed to find relevant material parameters and suitable equations and approximations. If time permits, the effect a TJ would have on the optical properties could be investigated using existing software developed by our group. This would involve simulating how the thickness and composition of a potential interlayer within the TJ, and the positioning of the TJ within the VCSEL, affect the optical absorption and thereby threshold material gain.

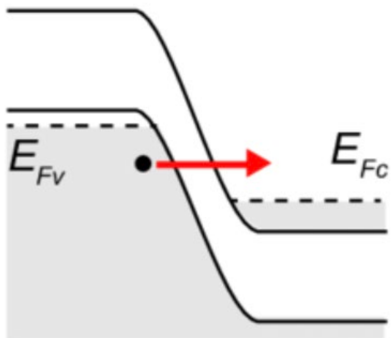

Figure 2. Band diagram of a reverse biased tunnel junction.

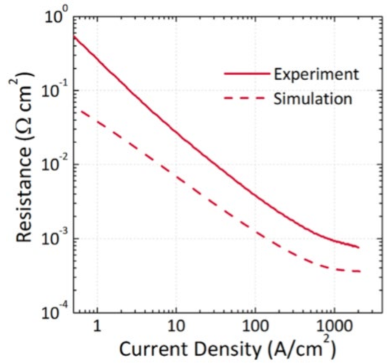

Figure 3. Simulated and experimentally measured tunnel junction (p-AlGaN/InGaN/n-AlGaN) resistance [1].

Contacts at the Photonics laboratory, Department of Microtechnology and Nanoscience
Main supervisor: Lars Persson (lars.persson@chalmers.se), Room: B443
Auxiliary supervisor: Filip Hjort (filip.hjort@chalmers.se), Room: B440
Examiner: Åsa Haglund (asa.haglund@chalmers.se), Room: B437

Reference

[1] Y. Zhang et al. "Interband tunneling for hole injection in III-nitride ultraviolet emitters". Appl. Phys. Lett. (2015.).

Further reading

S. Rajan and T. Takeuchi, "III-Nitride Tunnel Junctions and Their Applications", chapter 8 in *III-Nitride Based Light Emitting Diodes and Applications*, by T.-Y. Seong et al. (eds.), Topics in Applied Physics 133, Springer Nature Singapore Pte Ltd. 2017, DOI 10.1007/978-981-10-3755-9_8