Multi Section Bandgap Tuned Superluminescent Diodes Fabricated by UV Laser Induced Quantum Well Intermixing

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Abstract- **Superluminescent diodes are used in numerous sensing and testing applications. To achieve the wide emission spectrum and high power required from such devices, we studied an innovative design constituting in several different bandgap energy sections independently electrically pumped. Bandgap modification was obtained by the UV laser quantum well intermixing process.**

I. INTRODUCTION

Superluminescent Diodes (SLDs) find numerous applications, ranging from medical imaging (e. g. Optical Coherent Tomography) to optic devices characterization, as well as sensing applications (gyroscopes, fiber sensors). For those applications, high power and broadband emission are major parameters. In previous works, Multi Section Superluminescent Diodes (MSSLDs) have been studied as a way to deliver large spectral width without sacrificing power emission. Indeed, this type of device allows the excitation of both ground state and excited state on different electrodes. The principle was applied to quantum well [1] and quantum dot [2] [3] [4] based materials.

We are proposing here an innovative use of the MSSLD design: thanks to the UV Laser Quantum Well Intermixing (UV-QWI) process developed at Université de Sherbrooke [5], a SLD consisting of several different bandgap energy sections was developed, each section being driven by a different electrode, allowing an important versatility on output spectral width and power.

II. DEVICE SIMULATION

A. General considerations

Simulations were realised to evaluate the potential efficiency of this design. The device we considered to develop is a four electrically independent sections SLD, one being an absorption section (to which a reverse bias can be applied) to minimize spectral ripple due to reflections. The other three sections are active sections of similar length, but with different quantum well bandgap profiles (see Figure 1). The structure used is an InGaAs/InGaAsP five-quantum wells laser structure grown on an InP substrate by Metal organic Chemical Vapour Deposition, with a photoluminescence (PL) peak wavelength measured at 1535 nm at room temperature. Thanks to the UV-QWI process, this value can be locally blue shifted up to 120 nm.

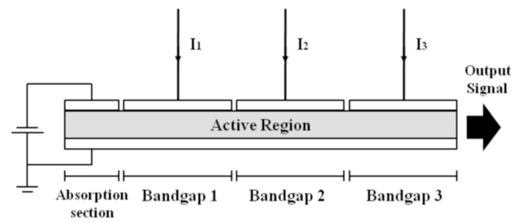

Figure 1. Multi Section SLD profile

To simulate the behaviour of our device under different current injection, the traveling wave (1) and carrier density rate (2) equations were used [6-7]:

$$\frac{1}{v_g}\frac{dE_j}{dt} \pm \frac{dE_j}{dz} = \left\{ -j\left(B + \frac{1}{2}Tag_m\right) + \frac{1}{2}(Tg_m - a_s) \right\} \times E_j + S \cdot \quad (1)$$

$$\frac{dn(z)}{dt} = \frac{I}{edLW} - R(n) - \frac{T}{dW}\left\{ \sum_{k=1}^{N_s} g_m(v_k, n)(N_{s_k}^{+}(z) + N_{s_k}^{-}(z)) \right\}. \quad (2)$$

$$-\frac{2T}{dW}\left\{ \sum_{j=0}^{N} g_m(v_j, n(z))K_j((N_j^{+}(z) + N_j^{-}(z))) \right\}$$

where E is the traveling optical wave (frontward or backward), v_g the group velocity, B the propagation constant, T the confinement factor, g_m the material gain, a the linewidth enhancement factor, a_s the modal loss, S the spontaneous emission, n(z) the carrier density, $N_s(z)$ and N(z) the photon rates of signal and spontaneous emission ($N=|E|^2$), I the injected current, K the normalization factor of random spontaneous emission and L, d, W are the waveguide length, thickness and width, respectively. The equations can be simplified at steady state, when dn(z)/dt and dEj/dt are equal to zero. By combining equations (1) and (2) with boundary conditions; we can calculate the SLD emission spectrum. Calculation parameters were chosen to simulate a behaviour close to actual structure's one.

B. Calculations for 3-sections of same length

We studied the 3-sections case built in a 5 µm wide ridge waveguide, the active sections being 1 mm long each. The electroluminescent peak wavelengths of the sections were 1550 nm, 1490 nm and 1430 nm respectively. These three values were chosen to offer a maximum gap between their QW gap

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energy (as much as can be offered by the UV QWI process on this type of structure).

First, the output spectrum from a single bandgap energy SLD of 3 mm was compared with the spectrum from the three 1 mm long sections of different bandgap energy device described previously; with a current density similar for both SLD from as grown material and bandgap tuned material.

The results (Figure 2) demonstrate that this last spectrum is broader thanks to the addition of each section spectrum. However the power spectrum from this three different bandgap sections also shows that the emission from the second section dominates the output power spectrum.

To obtain almost flat top spectrum, we increased the injected current in the first and third section as shown in Figure 3. We noticed that both the output power and full width at half maximum (FWHM) have been enlarged. The power increment from section 1 with the same current increment is larger than section 3, the amplified spontaneous emission from section 1 being amplified by both section 2 and section 3.

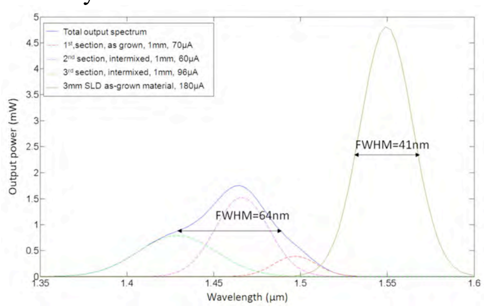

Figure 2. Comparison of two single electrode SLDs, one as grown, one bandgap tuned with 3 different sections of same length

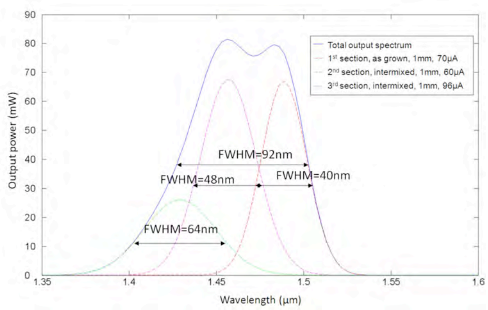

Figure 3. Optimized output spectrum by current tuning

III. 3-Sections Device Fabrication

On the top of the 5-QW InGaAs/InGaAsP laser structure, a 200 nm thick undoped InP layer was grown. This sacrificial layer plays an important role in the UV-QWI process. Irradiation by an UV laser is performed to generate defects in this layer. The structure is then annealed and intermixing of the quantum well and barrier materials takes due to the diffusion of point defects generated by the laser/surface interactions.

The sample was irradiated by an ArF excimer laser (λ=193 nm, τ=15 ns) at 90 mJ/cm². An optical system homogenizes the beam at laser output for a uniform spatial energy distribution. Different masks can be placed on beam path to deliver desired patterns on the irradiated sample surface. The number of pulses delivered to each sample region was set to obtain desired blueshift. In this study, a 1 mm large rectangular beam was projected on the sample surface (corresponding to the bandgap section width we designed). After irradiation, the sample was treated in a Rapid Thermal Annealing system at 700°C for 120 seconds. The blue shift was then characterized by PL-mapper. Following a chemical etching of the first InP sacrificial layer (consequently removing the macroscopic defects that may have been generated by laser irradiation), ridge waveguides were etched on the sample by Inductively Coupled Plasma (ICP). After insulator deposition and etching of injections lines, the highly doped contact layer was removed at the interface between each section to ensure electrical insulation. Electrodes were then deposited by evaporation and separated by lift off. Finally, after thinning and polishing of the sample to obtain a better cleave quality, the backside electrode was deposited and the device properties were tested.

IV. Conclusion

The preliminary results of design and simulation of multi-contact ridge waveguide SLD bandgap engineered by UV laser induced QWI are presented here. The output spectrum tunability range allowed by multi electrodes pumping of the different bandgap energy sections was more particularly studied. It clearly demonstrates the advantages that could be obtained from using bandgap tuned multi sections devices.

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