High-Confinement Strained MQW for Highly-Polarized High-Power Broadband Light Source

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***Abstract* — This letter presents highly-polarized edge light emitting diodes with high-confinement, strained, multiple quantum well active regions. We demonstrate +40dB of polarization extinction along with 16dBm of output power from an 800µm long centered quantum well device. By characterizing the polarization extinction and gain of devices with different lengths and optical confinement, we show that the polarization extinction is dominated by the polarization sensitivity of the gain.**

***Index Terms* — Polarization, ELED, photonic ICs.**

As photonic devices evolve towards highly-integrated architectures, polarization control of the optical signal becomes increasingly difficult. This results from a lack of chip-level polarization management components that can provide very high extinction between the transverse electric (TE) and transverse magnetic (TM) polarization modes. Most available on-chip polarization solutions utilize either interference effects or mode sorting effects to split polarization modes [1]. However, to the best of our knowledge, these devices have not demonstrated polarization extinctions in excess of about 20dB in InP [1,2].

In devices that require very high polarization extinction, such as a fiber-optic gyroscope (FOG), greater polarization extinction is needed. The FOG operates based on the Sagnac effect and thus requires high sensitivity to accurately sense small rotations [3]. Even with 30dB of polarization extinction, RMS noise from polarization induced signal drift approaches 10°/h [4]. Considering that a quality FOG should sense rotations on the order of 10^{-2}°/h, the need for a highly polarized optical signal is clear [3].

The use of a highly-polarized on-chip light source such as a strained multiple-quantum-well (MQW) laser is another option for achieving high polarization extinction. The addition of strain modifies the band structure, offering reduced threshold currents, higher output powers, and higher polarization sensitivity over unstrained lasers. Polarization extinctions of ~25dB have been reported from a compressively strained MQW laser [5]. However, due to it's the spectrally narrow output, a strained MQW laser would not suffice in applications where a broadband source is required, as in the Sagnac-loop based FOG [6].

In this letter we demonstrate high-optical-confinement, compressively strained MQW gain regions in edge light emitting diodes (ELED) for the generation of high power, broadband light with over 40dB of polarization extinction and 16dBm of amplified spontaneous emission (ASE) output power. We characterize InGaAsP MQW ELED devices with different lengths and optical confinement factors and show that the polarization extinction is dictated by the incremental gain of the ELED. The polarization extinction increases exponentially with device length and is roughly equal to the large signal gain of the device.

When strain is incorporated in the gain material, the light hole (LH) / heavy hole (HH) degeneracy in the valence band is lifted at the Γ point. The transition matrix element dictates that transitions involving the HH band provide gain/absorption to TE polarized light and those involving the LH band provide gain/absorption mostly to TM polarized light, and to a lesser extent to TE light [7]. Under compressive strain the conduction band (CB) -HH bandgap shifts to a lower energy than the CB-LH bandgap and the spontaneous emission spectrum generated under forward bias will be heavily TE polarized [5]. As the spontaneously emitted light propagates through the ELED, the polarization extinction of the TE to the TM mode will increase since the incremental gain provided by the strained MQW is highly polarization dependent.

Two different MOCVD grown strained MQW epitaxial designs were examined (Fig. 1). The first MQW consisted of ten InGaAsP 6.5nm compressively strained (0.9%) QWs and eleven 8.0nm tensile strained (-0.3%) InGaAsP barriers centered within two 105nm 1.3Q waveguide layers. This centered MQW (c-MQW) active region is designed to align the peak of the optical field with the MQW such that the modal confinement is maximized at ~13%. The second MQW design made use of seven wells and eight barriers of similar composition and thickness to the first design. However, in this structure the MQW was placed above a single 350nm thick 1.3Q waveguide layer. This offset MQW (o-MQW) active region provides an optical confinement of only ~6%.

For active/passive definition, a quantum well intermixing method described in [8] was used to shift the as grown c-MQW bandedge from a photoluminescence wavelength of 1520nm to 1400nm in the passive sections. The o-MQW device used selective removal of the offset wells as described in [8] to define passive regions. Using standard InP processing

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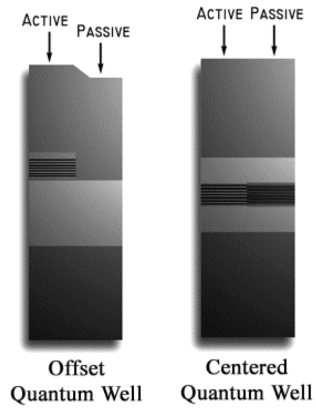

Fig. 1. Side-view schematic of MQWs used for ELED fabrication. The o-MQW (left) has a 6% confinement factor and the c-MQW (right) has a 13% confinement factor.

techniques, we fabricated 3μm wide surface ridge devices. The devices consisted of an ELED and an integrated photodetector separated by a short passive section (Fig. 2). The reverse biased photodetector was used to measure the ASE power generated in the forward biased ELED. The passive output waveguide employed a curved/flared design along with an anti-reflective coating to reduce reflections and improve fiber coupling efficiency.

We characterized the ELEDs in terms of polarization extinction, gain, detected output power in the photodetector, and the full width at half maximum (FWHM) of the output spectrum. Fig. 3 shows the TE and TM polarization-resolved ASE spectrums from two c-MQW ELEDs at 1.7kA/cm^2/well. The output of the ELED was collimated through an objective lens into a Glan Thompson prism to split the polarization states, and then coupled into a multi-mode fiber. Because the CB-LH transition occurs at a higher energy than the CB-HH transition, the peak of the TM spectrum is shifted to a shorter wavelength (~1450nm) than that of the TE peak (~1520nm). The 200μm long device (Fig. 3a) demonstrates a TE peak power of -67.5dBm while the TM mode demonstrates a peak of -79dB, indicating 11.5dB of polarization extinction. Fig. 3b shows the ASE spectrum from an 800μm long c-MQW ELED device exhibiting +40dB of polarization extinction with the peak of the TE mode at -38dBm and the TM at -80dBm. The longer wavelength peak appearing in the TM resolved plot is an artifact of our polarizing prism, which itself was only capable of providing ~27dB of polarization extinction. Also shown in the figures are ASE spectrums measured without the polarizer. The TM mode appears as a well-aligned shoulder in the non-resolved spectrum demonstrating that the coupling efficiency was not affecting our extinction values.

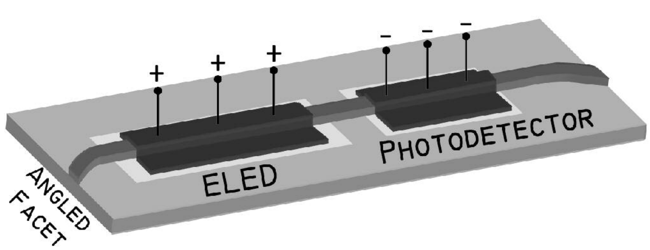

Figure 2. Schematic of ELED device illustrating the integrated photodetector and angled output facet.

The polarization extinction for c-MQW devices with lengths of 200μm, 400μm, 600μm, and 800μm are plotted in Fig. 4. As seen in the figure, the extinction is increased by ~10dB per 200μm of ELED length. The TM power remained constant at ~-80dBm in all cases, indicating that the compressively strained MQW essentially provided no incremental gain to the TM mode. Fig. 4 also shows the polarization characteristics of o-MQW devices with lengths 400μm, 600μm, and 1000μm at a current density of 1.4kA/cm^2/well. These devices clearly do not provide the same degree of polarization extinction as the c-MQW devices, with a slope of only 10dB per 500μm of ELED length. In fact, the 1000μm long o-MQW device provides the same extinction as the 400μm long c-MQW device. Since the c-MQW device possesses an optical confinement factor (and hence an incremental gain) of over 2X that of the o-MQW device, the extinction improvement scales closely with the higher gain offered by the c-MQW ELED. The slightly higher current density per well on the c-MQW ELEDs likely adds to this effect.

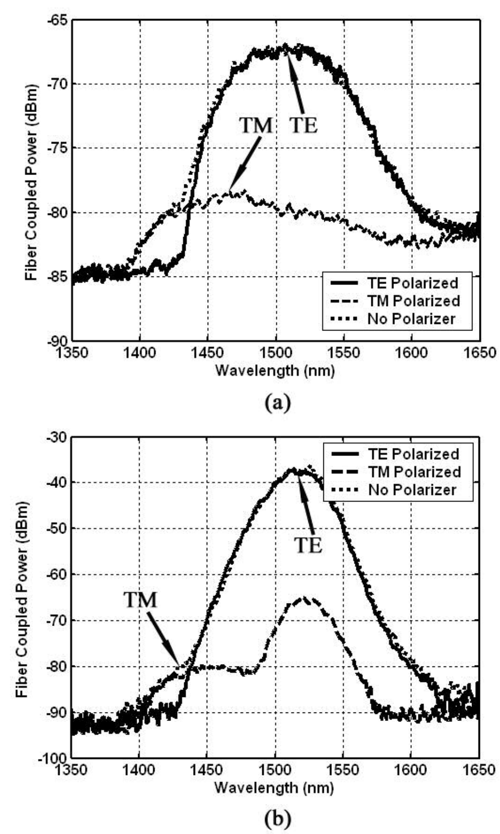

Fig. 3. Output ASE spectrum from (a) 200μm long device and (b) 800μm long device c-MQW device biased at 1.7Ka/cm^2/well. The figures show spectra for the TE resolved state (solid), TM resolved state (dashed), and non-resolved state (dotted).

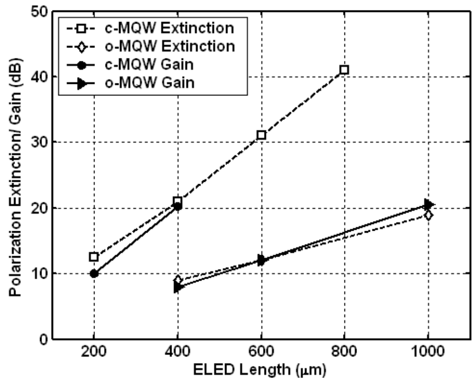

Fig. 4 The polarization extinction (dashed) and large signal gain (solid) for various length ELEDs using a c-MQW biased at 1.7kA/cm^2/well and an o-MQW biased at 1.4kA/cm^2/well.

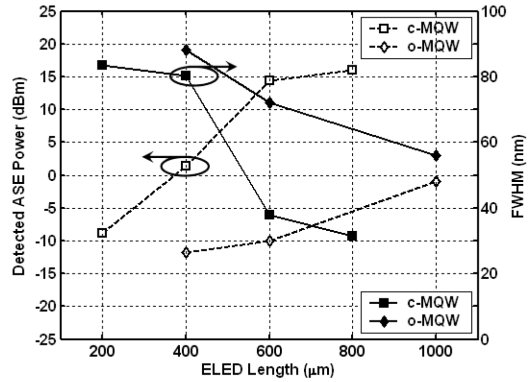

Fig. 5 The ASE power (dashed) and FWHM (solid) for various length ELEDs using a c-MQW biased at 1.7kA/cm^2/well and an o-MQW biased at 1.4kA/cm^2/well.

A 1548nm continuous wave (CW) TE signal was coupled into the ELEDs from lensed fiber to characterize the TE gain of the devices. The chip-coupled input power was first determined by reverse biasing the ELED. Then, with the photodetector under reverse bias, a forward bias of the same current density used in the polarization experiment was applied to the ELED. The gain was calculated by comparing the input power to the photodetected power with the forward biased ELED (Fig. 4). Clearly, there exists a strong correlation between the gain and the polarization extinction, with the c-MQW device providing ~10dB of gain per 200μm and the o-MQW device providing 10dB of gain per 500μm of length. This indicates that the polarization extinction in the ELED is dictated by the polarization dependent gain and not by the polarization of the initial spontaneous emission.

The ASE power collected in the reverse biased (-3V) photodetector is plotted in Fig. 5 for both ELED types. The c-MQW device generates orders of magnitude more ASE power than the o-MQW device at a fixed length due to the higher incremental gain. The output ASE power increases from -8dBm in a 200μm long device to 14dBm in a 600μm long c-MQW device with a slope of ~11dBm/200μm, but then only increases to 16dBm for an 800μm long device. The roll-off in output ASE power is a result of gain saturation in the ELED. The 3dB output saturation power was measured to be ~15dBm and 14dBm in the c-MQW and o-MQW ELEDs, respectively. Since the generated ASE power in the 600μm and 800μm long c-MQW ELEDs surpasses the saturation power, the large signal gain to the input signal was compressed, explaining the use of only two points in the c-MQW device gain plot of Fig. 4. Beyond a c-MQW device length of 800μm, we would expect to see a compression in the polarization extinction as the gain provided to the ASE is compressed due to the ASE itself. By employing a wider waveguide the saturation power and the ASE output power could be improved [9].

The tapered superluminescent diode reported in [10] had a maximum ASE power of ~23dBm under quasi pulse testing at an applied current of ~6A. Our ridge device demonstrates a CW output power of 16dBm at a current of 410mA, which is 6X lower than the drive current required by the tapered device (2.5A) for the same output power. Furthermore, our 3μm wide ridge ELED tapers to only 5.6μm, enabling a higher fiber coupling efficiency than the 130μm tapered output in [10].

In Fig. 5 we also show how the FWHM of the output spectrum decreases with ELED length. This is a result of the wavelength dependent gain properties of the MQW. However, the c-MQW ELED offering ~40dB of polarization extinction still provides more than 30nm of bandwidth. This could be increased with an alternate quantum well design.

We have demonstrated strained MQW ELEDs for a high power broadband light source offering +40dB of polarization extinction. Since the polarization extinction and output power of the ELEDs scale with incremental gain, we confirm that using a maximum confinement c-MQW active region provides superior ELED performance over that of an o-MQW device.

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