Very High Power 1310nm InP single mode Distributed Feed Back Laser Diode with Reduced Linewidth

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Introduction

High power single mode InGaAsP/InP DFB laser diodes with narrow linewidth and emitting near 1310nm are key devices for Analog transmission and Sensor applications since they can be rugged and compact sources more suited to harsh environment than solid-state or fiber-based lasers. Typically, the useful output power of DFB sources is limited to about 100mW when sub-MHz linewidth is required Ref [1] by the so-called “re-broadening effect” which causes the spectral linewidth to increase due to spatial-hole burning and other effects. We report here sub-MHz linewidth at output power levels exceeding 500mW resulting from cavity design that successfully addresses the concerns of linewidth re-broadening. Single-frequency operation can be maintained from threshold to the high power operating point without mode hops.

Device design

The design of high power narrow DFB has to address both the problems of obtaining a high slope efficiency and linearity over a large range of driving current as well as limiting the re-broadening effect which drives the linewidth of the emitted laser mode. The problem of designing a very high power DFB is that the linewidth tends to re-broad when the power exceeds typically a few tens of mW. This re-broadening is mainly caused by the spatial hole burning in the carrier density along the laser when the optical field increases. The optical field along the cavity of DFB is generally not flat and this non-flatness get worse with increasing power then causing index modulation along the cavity. Aside from spatial hole-burning it is also recognized Ref [2] that spontaneous recombination of carriers in the barriers or in the confinement layer can contribute to the re-broadening through phase noise, due to the stochastic nature of spontaneous recombination. Even if it is not recognized as the major contributor to the re-broadening of the linewidth, this latter effect can not be ignored.

Without considering the re-broadening effect, the linewidth is given by the following expression:

$$\Delta \nu = \frac{(1 + \alpha^2)}{(4 \Pi P) Nsp (hv) v_g^2} \alpha_m (\alpha_m + \alpha_i)$$

Where:

- $\alpha$ is the linewidth enhancement factor
- $P$ the total facet power emitted by the device
- $Nsp$ the spontaneous emission factor
- $\alpha_m$ the mirror losses (R/L)
- $\alpha_i$ the internal losses
- $v_g$ the group velocity
From this equation, it is advantageous to increase the length of the device in order to reduce the mirror losses. The linewidth enhancement factor can be reduced by detuning the lasing wavelength on the red side of the gain bandwidth in order to increase the differential the gain and also by making use of compressive strain in the MQWs. Using parameters found in the literature and the above expression with a 1.5 mm cavity, the linewidth should be in the order of 25KHz which is more than an order of magnitude less than any results reported so far. This suggests that the re-broadening is clearly the main limiting factor to achieve narrow linewidth in semiconductor DBF laser as described in Ref [1].

The design of a narrow linewidth and high power DFB should therefore focus on limiting the re-broadening effect to maintain narrow linewidth emission. Part of the strategy involves optimizing the design to obtain high slope efficiency as well as maintaining good linearity over a broad range of driving current. In addition, kink occurrence has to be delayed as much as possible in order to offer a kink free operation in the most linear part of the light versus current emission curve.

It has been reported by K.Takaki in [1] that re-broadening decreases with $L^2$ since local photon density vary more gently in a longer cavity, therefore the cavity length has to be increased has much as possible to reduce the re-broadening effect. But it is also admitted that re-broadening effect is mainly due to Spatial-Hole-Burning (SHB), also our design approach seeks to achieve “as flat as possible” optical field along the laser cavity. A low flatness value is also important to achieve kink free emission over a large range of power since Spatial-Hole-Burning is also responsible for local index change, through carrier depletion effect, which in turn can cause a mode hop. It is well known that optical field flatness in a DFB with a uniform grating layer is mainly determined by K.L value, where K is the grating coefficient and L the length of the laser cavity. Facets reflectivity and the phase of the cleaved facets relative to the period of the distributed grating as described in Ref [1] also contribute to achieving optical field flatness.

In order to simplify our analysis we will restrict our discussion to DFB configuration based on a uniform grating together with an Anti-Reflection (AR) coating on front facet and a High-Reflection (HR) coating on the back facet. This simple configuration has proven to be the most efficient one to achieve high slope efficiency value since it forces the light to be emitted from the AR coated facet. We have also limited our analysis to the case where the facet reflectivity of the front facet is very low so that its contribution is relatively minor but not neglected in our analysis. Figure 1 represents the flatness of the optical field versus the phase of the back facet with respect to the grating for different value of the K.L. The best flatness is obtained for a K.L value around 0.7. For this value, the flatness is very low for any value of the phase corresponding to a high gain margin (Figure 1). As the phase at the facet is essentially random, the low dependency of the flatness with respect to the facet phase and especially for the phase values (0 to 200 deg) where the gain margin is high which is a very good point to achieve reasonable yield of kink free devices with consistently narrow linewidth.
Figure 1: Calculated Flatness and Gain margin with Back facet phase relative to grating for K.L product of 0.5, 0.7 and 1.

Having selected a target K.L value, the design now addresses the detailed laser cavity. Since the re-broadening is due to an increase of the photon density in the laser cavity, a classical high power laser diode approach of expanding mode volume through cavity dimensions can be taken, providing that the cavity losses remain constant.

Our 14XX nm Raman Pump (JDSU 3400 Series) platform indicates that cavity length in the range of 2mm can yield slope efficiency higher than 0.4mW/mA, implying optical losses in the range of -5 cm⁻¹. Such low value of losses can be achieved through careful management of doping and quantum well design in the active region. Optical losses are even lower around 1310nm since the inter-valence band absorption, which is the main cause of optical losses in InGaAsP/InP system, tends to decrease when moving towards short wavelengths. As a result, long cavity lasers can be designed while maintaining high slope efficiency.

Power scaling of the DFB also involves selecting a large mode area waveguide structure to produce low photon density and low current densities at high output powers. Using a planar, weakly-index-guided structure, we can expand the optical mode to a degree while suppressing the occurrence of the 2nd order transverse mode. The large optical cavity design serves to reduce series resistance, thermal resistance and provides a relatively low divergence angle output beam for improved fiber coupling efficiency.
For high performance under continuous wave (cw) operation, the devices are soldered P side down onto expansion-matched carriers that provide both a good thermal conductivity while avoiding stress build-up between the laser and the carrier.

Results and discussion

We have compared two different cavity lengths (1.5 and 2 mm) at constant K.L value around 0.7-1. Typical CW light versus current characteristics at 25°C is reported in Figure 2.

![Figure 2: CW Light / power characteristics for 1.5 mm and 2 mm long chip on carrier for constant K.L value around 0.7 measured at 25°C.](image)

Slope efficiency greater than 0.5 W/A, which results in output power in excess of 500mW at current around 1200mA, is achieved for both 1.5 and 2 mm cavity lengths. More than 600 mW output power is produced by the 2mm design at 1600mA. Note that the thermal roll-over measured on a chip-on-carrier is rather pessimistic since the carrier is only mechanically clamped onto the heat sink, resulting in relatively high thermal resistance and high self heating. Assembly into packaged modules, where the carrier is soldered onto the heat sink, results in more linear light versus current characteristics than for chip-on-carrier.

Excellent device performance is observed from these DFB lasers across an operating range from near lasing threshold up to the thermal roll-over of the light versus current characteristic. Pure single longitudinal mode emission can be observed at any power through high resolution spectrum measurement at different driving currents (Figure 3). While similar output power levels have been previously reported in Ref [3&4], our result is the first report of single frequency and narrow linewidth performance obtained at these power levels.
Spectral linewidth are reported in Figure 4 for both 1.5 and 2 mm design at different operating currents. The re-broadening effect can be clearly observed for current higher than 400mA. Narrower linewidth are observed on 2mm cavity design with a minimum close to 150 kHz. In comparison, minimum linewidth close to 250 kHz is observed for the 1.5 mm cavity design. The re-broadening with increasing power is relatively gradual, thereby maintaining the spectral linewidth below 300 kHz up to 500mW emitted power for the 2mm device, according to the L(I) curve reported in Figure 2.
Spectral linewidth was measured at different chip temperatures and is demonstrated to be fairly insensitive to temperature between 25 and 45°C (Figure 5). This last point is important since it provides some degree of fine wavelength tuning important in some applications.

Packaged modules have been assembled with 1.5 mm long devices. Results with packaged 2mm long devices will be presented at the conference since there were not available at the time of submission. Coupling efficiency greater than 70% has been demonstrated into polarization-maintaining fiber. Optical power as high as 300mW ex-fiber is achieved at current less than 1 Amp (Figure 6).

Figure 5: Linewidth versus current at different chip temperature

Figure 6: Packaged module L(I) at 25°C
RIN measurement indicates close to shot noise limit emission, with values of -130dB/Hz are observed from 100 kHz to 1MHz. (Figure 7) and -150dB/Hz from 10MHz to 20GHz (Figure 8).

**Figure 7: 100KHz-1MHz RIN measurements at 1Amp**

**Figure 8: 10MHz to 20GHz RIN measurements at 1Amp**

**Conclusion**

We have demonstrated InGaAsP/InP DFB laser diodes emitting more than 600 mW cw around 1310nm. Spectral linewidth below 500 kHz is maintained across a wide operating range due to the effectiveness of a large cavity design that provides a highly uniform optical field along the length of the device. Fiber coupled powers higher than 350mW are demonstrated in packaged modules at 1.2 Amp drive current. The combination of optical power, spectral purity and power efficiency make this laser an ideal compact rugged source for analog transmission, telemetry or sensing applications.

**References**

