InP-based Long Wavelength Sources for Solid State Lasers Pumping

D. Garbuzov
Princeton Lightwave Inc. 2555 Route 130 South, Suite 1, Cranbury NJ 085612
M. Dubinskii
U.S. Army Research Laboratory, AMSRD-ARL-SE-EO, 2800 Powder Mill Road, Adelphi, MD 20783

For GaAs-based diode lasers (DL) operating in the 790 – 980 nm range, major power limitations are associated with catastrophic optical degradation (COD) of mirror facets and, measurably, other reliability issues. Reliability concerns do not limit the performance of InP-based diode lasers to such a large extent. The maximum power for these devices is determined by the "initial", near-threshold differential efficiency $\eta_{d\text{-}max}$ and the rate of $\eta_{d\text{-}max}$ reduction with increasing pump current (P-I characteristic rollover). Rollover effect is negligible in GaAs-based lasers since the T_0 and T_1 parameters characterizing the temperature dependencies of the threshold and η_d are much higher than those for InP-based emitters. Rollover power limitation can be reduced by using devices with long cavity length, provided the internal optical losses (α_{int}) are low and $\eta_{d\text{-}max}$ does not decrease considerably with increasing cavity length. Therefore, α_{int} reduction is a key to achieving high-power InP-based diode lasers.

The absorption loss analysis in InP lasers [1] shows that the absorption by free holes in the p-InP cladding layer and in Quantum Wells (QW) are the major loss mechanisms. So far, three approaches have been used to reduce absorption losses: (i) the thickness of undoped waveguide was increased up to 1300 nm to prevent the lasing mode penetration into the p-doped cladding layer (Broad Waveguide design) [2]; (ii) stepped acceptor doping profile in p-InP cladding was used in structures with narrow waveguide [3,4]; (iii) the number of QW was reduced from 3 to 2 in the last version of the narrow waveguide structures [4].

In this paper we present the parameters of recently developed InGaAsP/InP single element lasers and diode laser arrays emitting at ~1850 nm and ~1450 nm. For fabrication of 1850-nm emitters the structure with total waveguide thickness W=1000 nm (Fig. 1) was used. 1450-nm emitters were fabricated from the latest version of "telecom" structures with a total waveguide width of 60 nm. In both cases the undoped waveguide consists of InGaAsP layers of two compositions with band gaps of 1250nm and 1100 nm, respectively (Fig.1). The InGaAsP QW compositions were selected to provide the target laser wavelength as well as ~1% of compressive strain in the QW layers. The 100-μm active stripes were fabricated by the standard photolithography technique, which includes window opening in a Si_3N_4 dielectric layer. The center-to-center inter-stripe spacing for the 1850-nm and 1450-nm processed wafers were 1000 μm and 500 μm, correspondingly. The wafers were cleaved into 2 and 2.5 mm wide bars. The highly reflective (98%) Al_2O_3/Si coating and 3% low reflective Al_2O_3 coating were deposited on cleaved bar facets. The bars were chipped into single stripe lasers or into 1 cm long arrays. Both single emitters and arrays were mounted onto dielectric submounts with hard solder. The diode lasers with submounts were soldered to copper heat spreaders and then bolted to the TEC-cooled copper plate. Miniature thermocouples were used for temperature stabilization. The onset of the rollover at high driving current and the maximum power depend on the thermocouple positioning. E.g., the rollover starts at a higher current and the maximum power is higher if the thermal sensor is located on a dielectric submount compared to the case when the thermal sensor is mounted to the copper heat spreader.

1850 nm emitters. Fig 2 and 3 show the P-I characteristics for the 1850 nm single stripe emitter and 10-stripe array, respectively. The values of $\eta_{d\text{-}max}$ are about 45-47% for both devices. The obtained maximum powers of 1.6 W and 14 W, respectively, are, to our knowledge, record highs for DLs in this wavelength range. Comparison of the currents and powers for a single emitter and laser array shows that ~1 mm spacing is enough to avoid the cross-heating of the stripes in the arrays. Fig. 4 shows that the power conversion efficiency is close to 22% at 4 W output power but drops to 11% at the maximum power (at 15 times the threshold current).

The life-testing data are plotted in Fig. 5. To obtain the data, the array was run at 45 A, 110° C, then stopped every 100 hours and the P-I characteristic was re-measured at 25° C. Degradation rate at 110° C was found to be ~$5x10^{-5}$/h. Based on these results, and assuming that the degradation process activation energy for the structure with 1850-nm QW is the same as for 1450-nm QW laser structures, we infer the 10^6 hours device lifetime at 25° C before power decreases by 20%.

1450 nm emitters. Fig. 6 and 7 present the data for a 1460 nm single stripe and 20-stripe array emitters, respectively. These data refer to the devices fabricated from the best of approximately ten "telecom" narrow waveguide structures processed in this format. As seen from Fig. 6, the maximum power for single 100 μm aperture emitter with optimal 2 mm cavity length exceeds 3.5 W at 10 A pump current. The maximum array power is about 38 W at ~110 A current (Fig.7), which corresponds to a 5.5 A current through each stripe. The maximum power is limited by the TEC cooling efficiency. The near-the-threshold slope efficiency is 0.48 W/A, which corresponds to a $\eta_{d\text{-}max}$ of 55%. The array series resistance is 3.3 mΩ and voltage at maximum current is only 1.25 V (Fig. 7). Power conversion efficiency reaches 29.5% at 50 A and decreases by only ~1.5 % with further current increase. The power conversion efficiency vs current dependence for the 1450 nm array is "flatter" than that for 1850 nm array since the current through each stripe is less in case of 20-element array. Another noticeable feature of 1450 nm emitters is a low beam divergence in the fast direction.

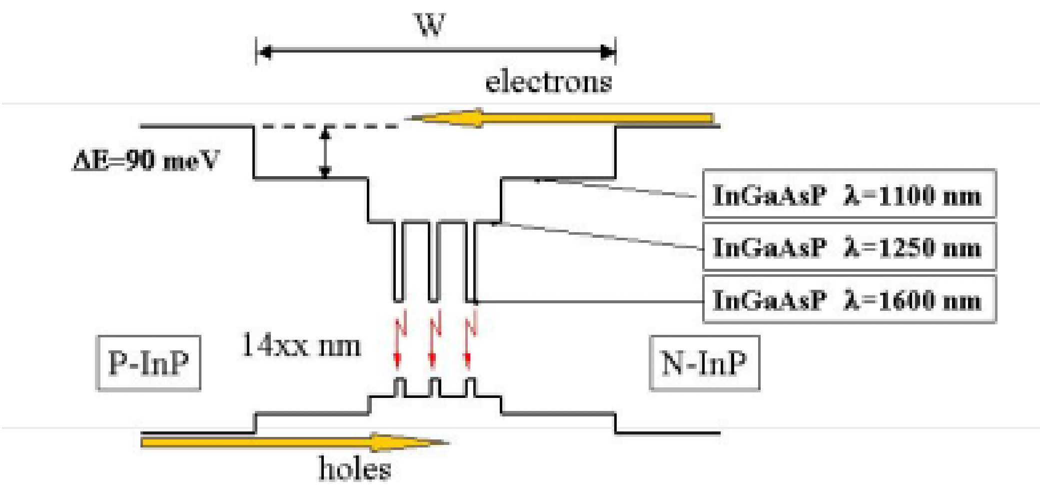
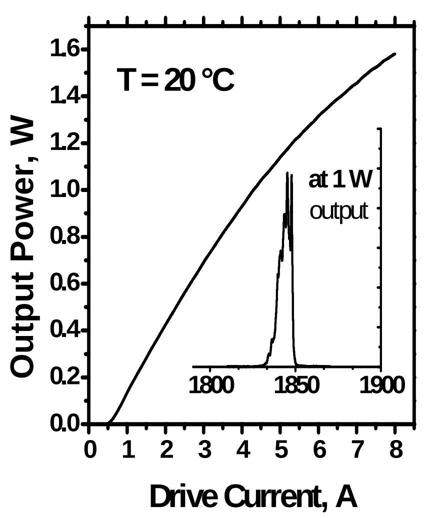


Fig. 1. Schematic band diagram of laser structure (not all structural layers are shown).



Fig, 2. P-I characteristic and spectrum for 1850 nm single emitter with 100 μm aperture and 2.5 mm cavity length.

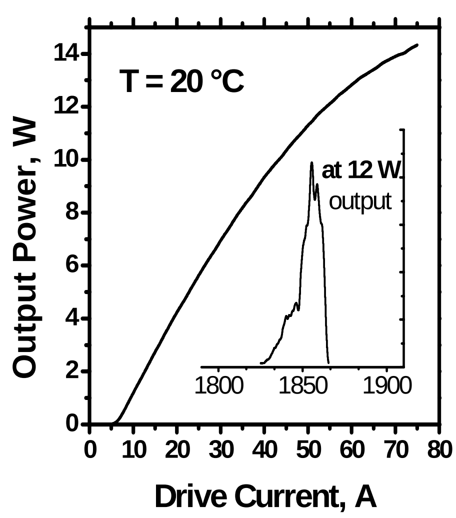


Fig. 3. P-I characteristic and spectrum for 1850 nm array. Array consists of 10 emitters with 100 μm aperture. Cavity length is 2.5 mm.

.

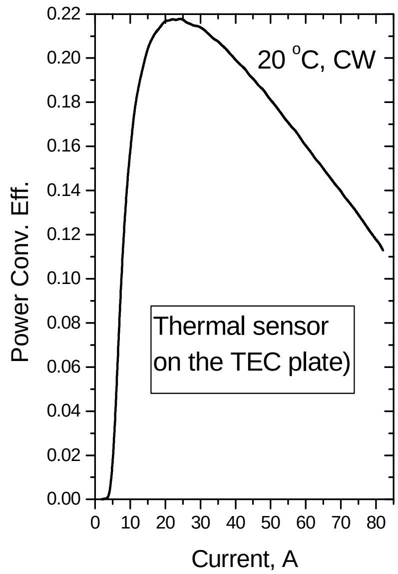


Fig. 4. . Power conversion efficiency as a
\ function of current for array of Fig 3.

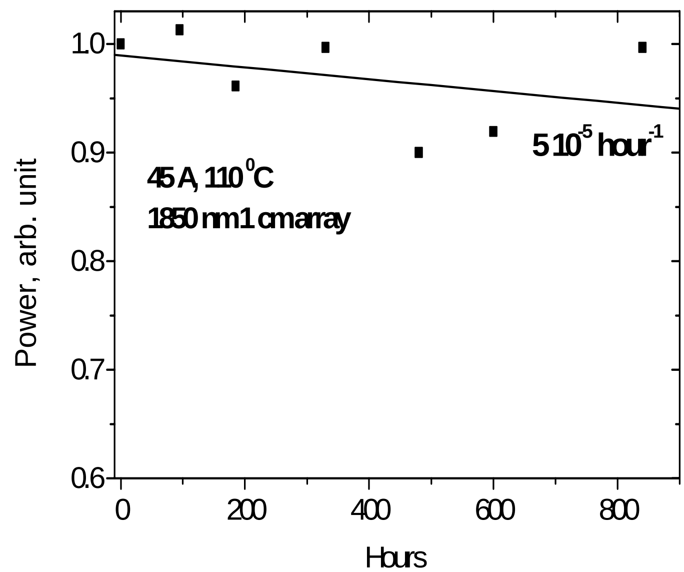


Fig. 5. The results of a 850 hour test at 110° C and 45 A for one of 1850 nm arrays.

Fig. 8 indicates that full width at half maximum (FWHM) for fast axis is 26° while in the lateral slow direction FWHM is 7°. Current level of DL beam shaping technology provides the efficient SSL pumping even when the fast axis FWHM is as large as 35-40°. This means that the InP-based laser structures have a potential for further increase in $\eta_{d\text{-max}}$ since the "pumping" laser structure can utilize a wider waveguide with much lover optical losses. The lifetime tests for several 1450 nm arrays were also conducted at 110 °C during 200-300 hours with a current of 40-50 A. Power reduction was not observed within the accuracy of our power re-testing measurements at 25 °C.

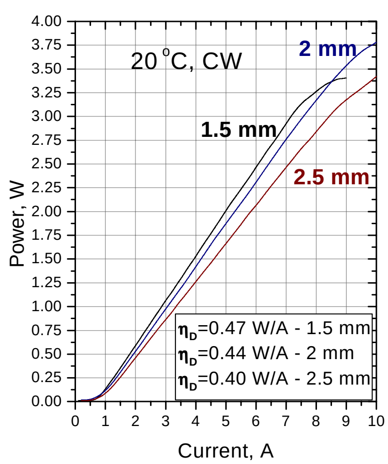


Fig. 6. P-I characteristic for 100 µm single 1450 nm emitters.

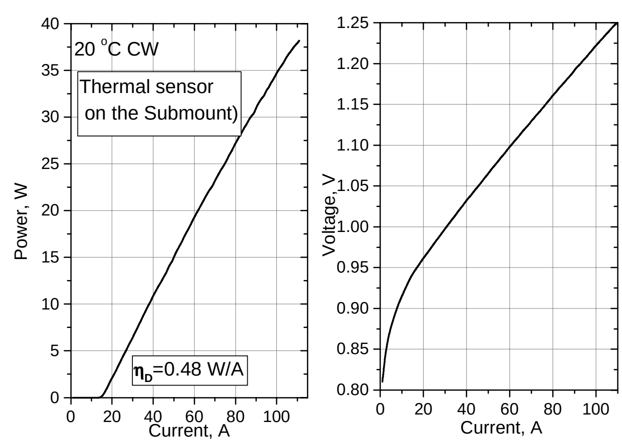


Fig. 7. P-I and I-V characteristic for the best of the tested 1450 nm array with 2 mm cavity.

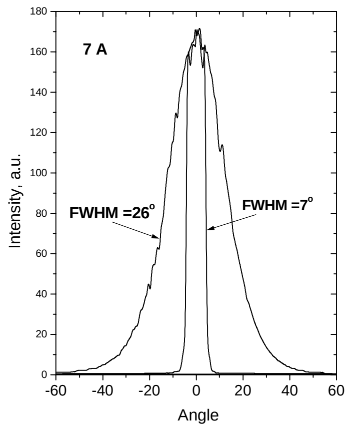


Fig. 8. Vertical and lateral far field distributions for a 1450 nm single stripe emitter.

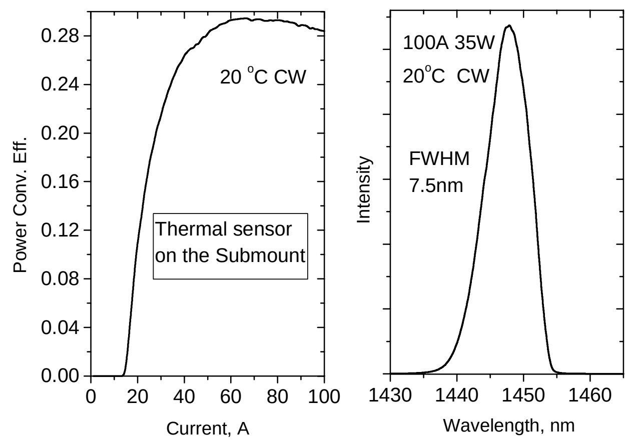


Fig 9. Current dependence of the power conversion efficiency and spectrum at 100 A for the best 1450 nm arrays.

Conclusion. If the compared pump sources have the same photon-to-photon pumping efficiency, it is clear that the photon flow, not power, should be compared in evaluation of device efficiency. Using this criterion, one can derive that both single and array 1450-nm emitters are superior to the commercial GaAs-based diode sources when used for pumping long-wavelength active media such as Er:YAG emitting around 1.6 μm. The maximum photon flow at output facets for 1450 nm sources is 30-40% higher than that for the commercial GaAs-based 2 W single elements or 50 W arrays. For 1850 nm sources, photon flux is ~50 % lower than that of GaAs emitters. The main advantage of using the InP-based DLs for Er:YAG pumping is the low photon defect and, as a result, dramatic reduction of active medium heat loading at high-energy operation, which carries a great potential for better laser beam quality. Despite the lower InP DL power conversion efficiency, the estimated overall efficiency of the Er-doped 1.6-μm SSL pumped with 14xx-15xx nm InP-based emitters is nearly identical to that achieved with GaAs 960-nm pumping. The drawback of InP DLs is associated with a stronger temperature dependence of their operating parameters than that of GaAs pumps. This drawback can be mitigated by thermal resistance reduction and by utilizing a better cooling system. An additional important positive feature of long-wavelength pumping sources is their excellent reliability with a potential for extremely long operation time (~10^6 hours). This operation time can be achieved without expensive mirror facet passivation thus making a mass production of InP sources more cost effective than that of GaAs-based pumps. The authors gratefully acknowledge A. Komissarov and I. Kudryashov for their technical assistance and helpful discussion of the results.

References

1. Ballman, A., Glass, R., Nahory, H. Brown, J., Cryst. Growth, vol. 62, p. 198, 1982.
2. D. Garbuzov, L. Xu, S. R. Forrest, R. Menna, R. Martinelli, and J. C. Connolly, Electron. Lett. 32, 1717 (1996).
3. D. Garbuzov, R. Menna, A. Komissarov, M. Maiorov, V. Khalfin, A. Tsekoun, S. Todorov, J. Connolly, Optical Fiber Communication Conference postdeadline papers, OSA Technical Digest Series, PD18 (Optical Society of America, Washington, D.C., 2001)
4. D. Garbuzov, I. Kudryashov, A. Komissarov, M. Maiorov, W. Roff, and J. Connolly, Optical Fiber Communication Conference OFC 2003, Invited papers, OSA Techn. Dig. Series, (OSA, 2003), WO1