Extremely Low Losses 14xx Single Mode Laser Diode leading to 550 mW Output Power Module with 0-75°C Case Temperature and 10 W Consumption.

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ABSTRACT

High power 14xx laser pumps are more and more required for eye safe industrial, medical, safety and defense applications as well as for increased telecom network capability (e.g. for 100 Gb Ethernet). However, this need of high power requires to control the overall power consumption in a range in line with systems requirements. In this respect, 3S PHOTONICS has developed a 14xx nm single mode laser diode with record internal losses of 1.5 cm^{-1} compared to the 2.7 cm^{-1} reported up to now. These lasers are based on p/nBH technology and use the asymmetric waveguide concept to reduce internal losses. The record loss value, coupled to an internal efficiency higher than 0.8, allows realization lasers of 3 mm length with external efficiency higher than 0.5 $W.A^{-1}$ at 25°C in AR/HR coating configuration. Modules using direct coupling technology were realized. High coupling efficiency is obtained thanks to the 8° x 14° far field pattern of the diode. Output power of 550 mW at 1.8 A is thus obtained, with or without FBG stabilization, with maximum output power above 700mW. Thanks to the lasers' length, voltage at this current level is below 1.9 V, which gives a reduced thermal load. Thus, the overall modules electrical consumption remains lower than 10 W at case temperatures ranging from 0°C to 75°C. The 3 mm length also guaranties high reliability of these laser diodes.

Keywords: 1480 nm, 14xx, laser diode, Raman amplification, FBG stabilized.

1. INTRODUCTION

High power semiconductor single-mode laser diodes are now widely used in several fields : medical, industrial, safety, defense and telecom. Long wavelength lasers are of particular interest for their "eye safe" properties [1]. In the telecom domain, the increasing traffic (+60 % per year since 30 years) drives the increase of the bit rate: while the installed systems work at 2.5 Gb/s and 10 Gb/s, 40 Gb/s and 100 Gb/s equipments are progressively installed. For these new systems, Raman amplification becomes very attractive to maintain the performances on long distances between the amplification stages. However, the power conversion efficiency of Raman pump surpasses the one of EDFA based pumps when the launched pump power is greater than 400 mW [2]. Thus, a bottleneck for a large scale deployment of Raman amplification is the availability of high power 14xx laser modules. Furthermore, low overall power consumption is a key issue to maintain the capability of these Raman amplifiers, as well as the capability to work at a case temperature of 75°C.

In this respect, the key point to fulfill the telecom system requirement is the availability of laser diodes with extremely low optical losses. Indeed, low optical losses allow to obtain high output power on one hand, and on the other hand this is done with long chips, which is essential to reduce both serial resistance and thermal load in the module and thus the overall device consumption. We have thus developed a 3 mm long laser diode with record losses of 1.5 cm^{-1}.

2. DEVICE DESIGN

2.1. Optical losses reduction

The device design of high output power InP laser diodes must identify the best compromises between many parameters: internal efficiency, optical losses, serial resistance, beam divergence, thermal behavior, thermal resistance… To achieve this trade-off, numerous variables have to be managed: material gain, Quantum Well (QW) type, QW number, doping levels, stripe width and length, facet coatings… The complexity derives from the fact that several opposite optimization

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routes coexist; as an example, achievement of low serial resistance requires high doping levels on the one hand while reduction of the optical losses requires low doping levels on the other hand.

Considering all these parameters, the first major issue to achieve high output power is the reduction of optical losses while maintaining a high internal efficiency. In InP, near 1480 nm wavelength, the optical losses are of the order of 10-15 cm^{-1} for a p-doping level of 1^{e18} cm^{-3}, while they are only of 1 cm^{-1} for a n-doping level of 1^{e18} cm^{-3}. A way to reduce internal losses is thus to pull the optical mode towards the n-side. This is done through asymmetric waveguides realized via a thick InGaAsP layer on the n-side. Meanwhile, the use of buried technology allows for both low thermal resistance and low serial resistance which is the second major issue. To avoid lateral current leakage of buried laser stripes, p/n BH technology has been applied to realize these devices. Figure 1 presents the vertical structure of a p/n BH laser with an asymmetric GaInAsP waveguide and the corresponding simulated optical mode. It clearly shows that a high proportion of the optical mode is set in the n-doped area.

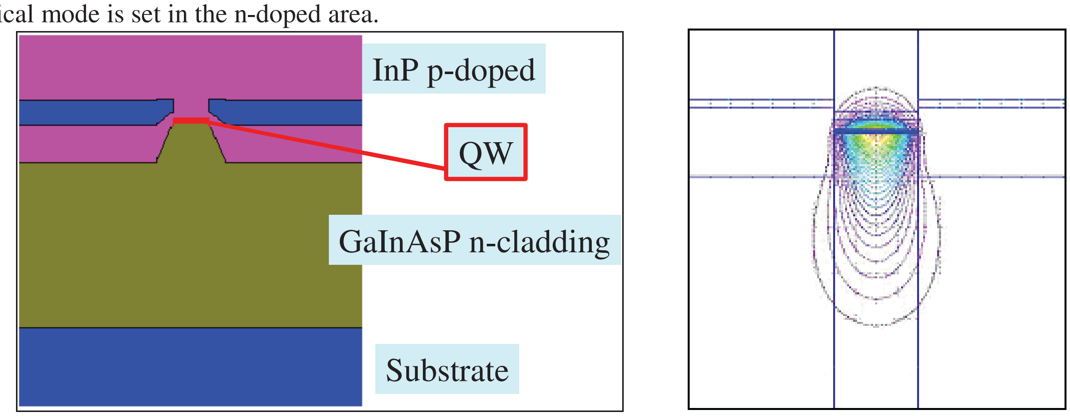

Figure 1. Schematic laser diode cross section (left). Simulated optical mode (right).

Using this design feature, optical losses of 5.1 cm^{-1} [3][4], 2.7-3.0 cm^{-1} [5] and 3.3 cm^{-1} [6][7]have been reported.

The third major issue is to ensure that the optical losses reduction is not obtained at the expenses of the internal efficiency. As already shown in [5] and [7], the composition of the GaInAsP layer has a strong impact on the optical losses through the optical confinement factor both in the active and InP p-doped regions. Figure 2 presents the effect of the composition of the InGaAsP cladding layer on the optical confinement factors in the active region and in the p-doped region. It can be clearly seen that both confinement factors are reduced but at different rates. Thus, above a specific value, the ratio between the two optical confinement factors reverse and optical losses will reduce more rapidly than the internal efficiency.

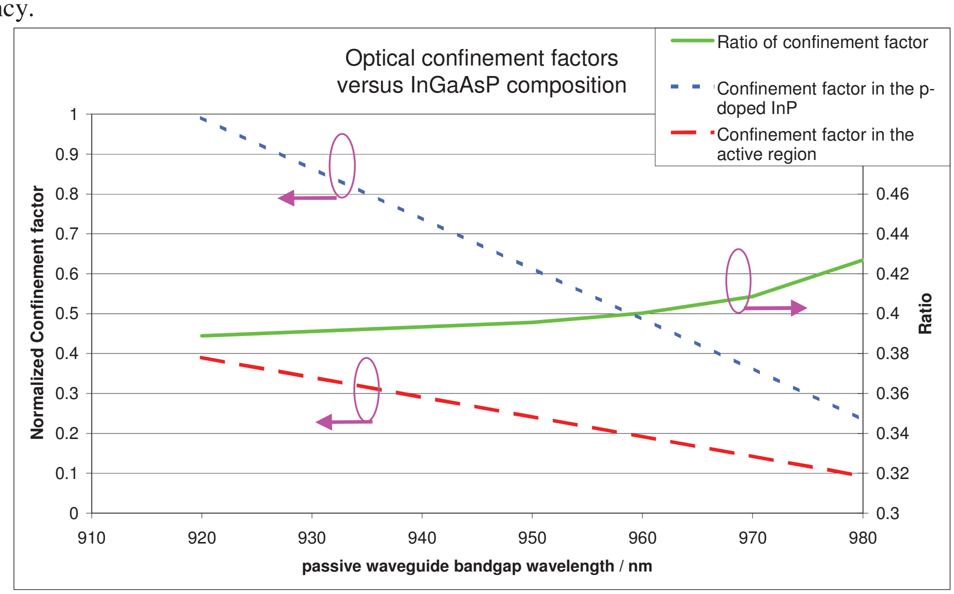

Figure 2. Simulated optical confinements factors in active region and in the p-doped InP versus the InGaAsP cladding composition.

An experimental study has been carried out in order to optimize the composition of the n-doped cladding. The p/n BH technology is described in [6]. In order to determine the internal losses and internal efficiency, chips of different lengths were realized and analyzed. Typical L(I) and V(I) curves of as-cleaved devices are shown on Figure 3. Short lasers (1.8 mm long) present a higher Slope Efficiency (SE) near threshold but a more rapid decrease in output power due to thermal effects. On the other hand, 3.6 mm long laser shows a lower SE near threshold but a much better thermal behavior. Meanwhile, the voltage at high current decreases as the serial resistance decreases for long devices.

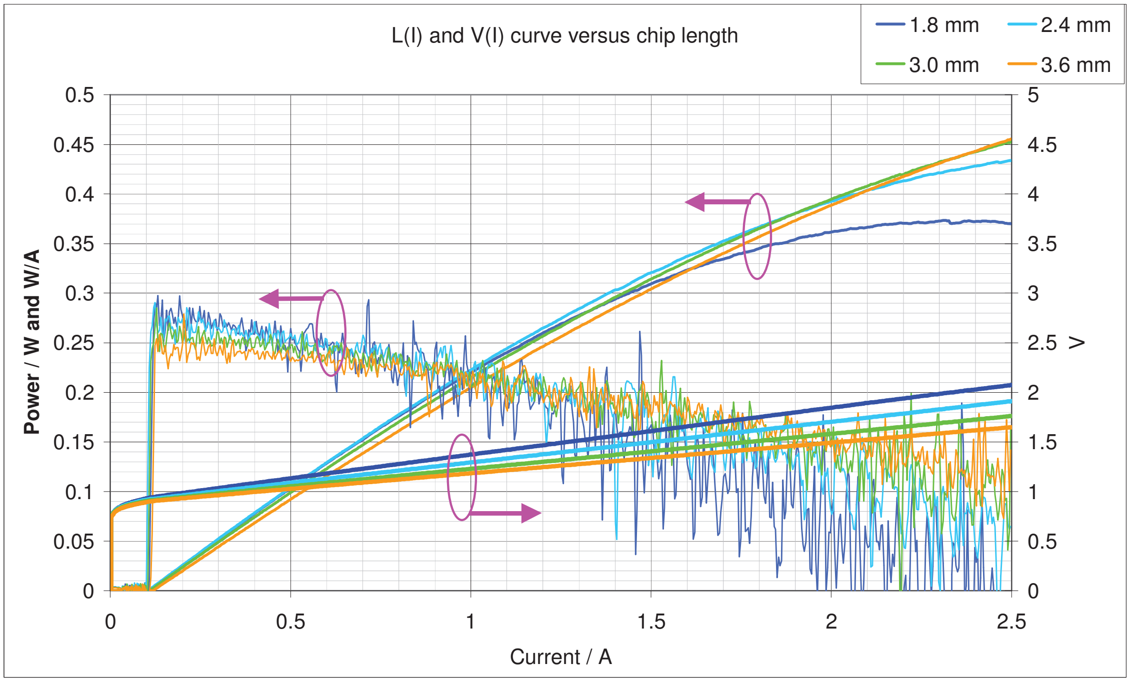

Figure 3. L(I), dL/dI(I) and V(I) curves versus length.

Figure 4 presents the evolution of the measured internal losses versus the composition of the cladding obtained with this method. The initial losses of 7 cm^{-1}, observed when a cladding near InP composition is used, can be reduced down to 1.5 cm^{-1}. These low internal losses almost reach the limit which is obtained when all the optical mode would be in the cladding. However, increasing the confinement factor in the n-cladding results in a decrease in the internal efficiency. This is shown in Figure 5.

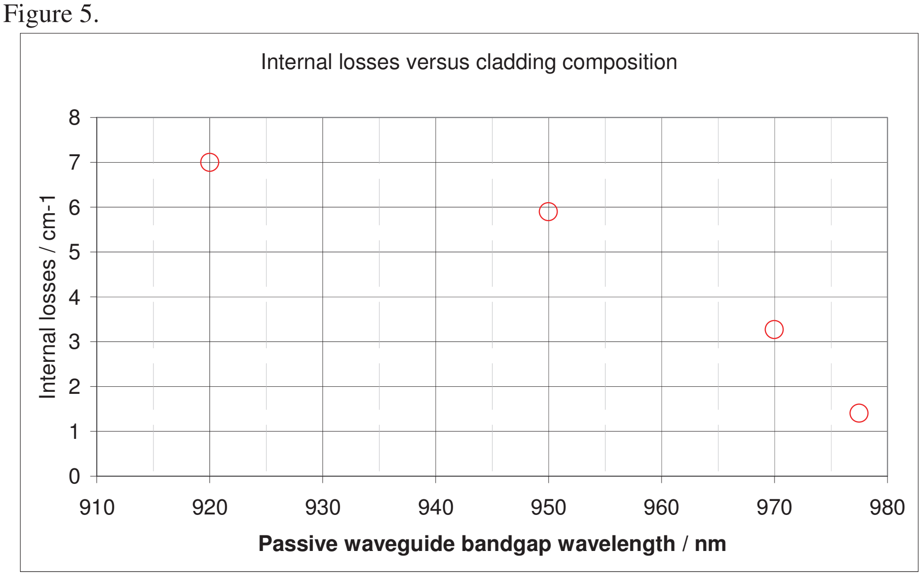

Figure 4. Internal losses versus InGaAsP cladding composition.

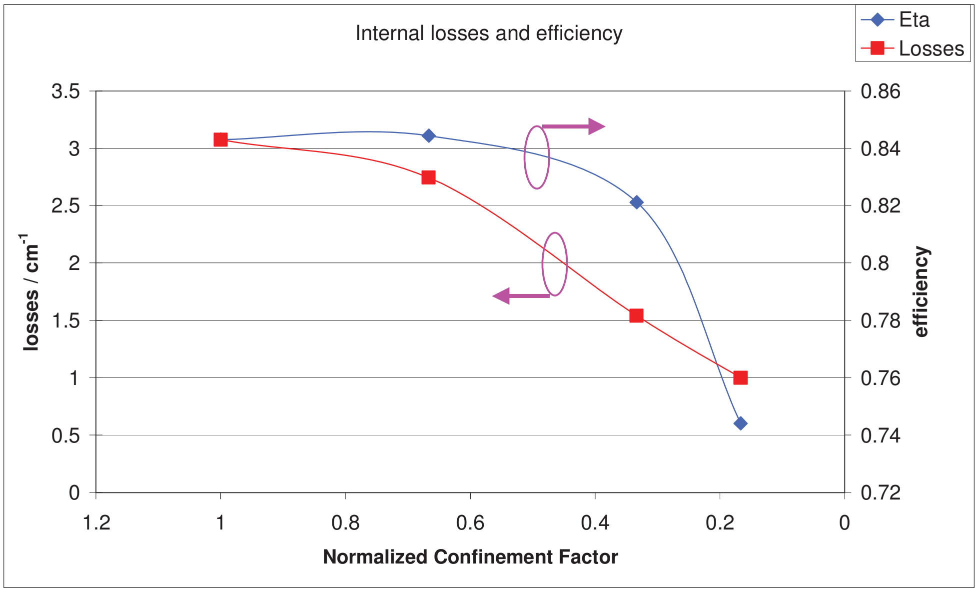

Figure 5. Internal losses and internal efficiency versus optical confinement factor in the cladding.

2.2. Laser characteristics

The best trade-off is obtained when we reach an internal efficiency of 0.82 and internal losses of 1.5 cm^{-1}. Using this design, laser diodes of 3mm long were realized and AR/HR coated. The chips were mounted p-side down in order to reduce the thermal resistance. Such long devices have a thermal resistance which is low enough to avoid the use of a costly diamond heat-sink on the AlN submount. Typical L(I) and V(I) curves of these devices are shown on Figure 7 at 25°C. A maximum output power exceeding 0.9 W above 3A is steadily obtained.

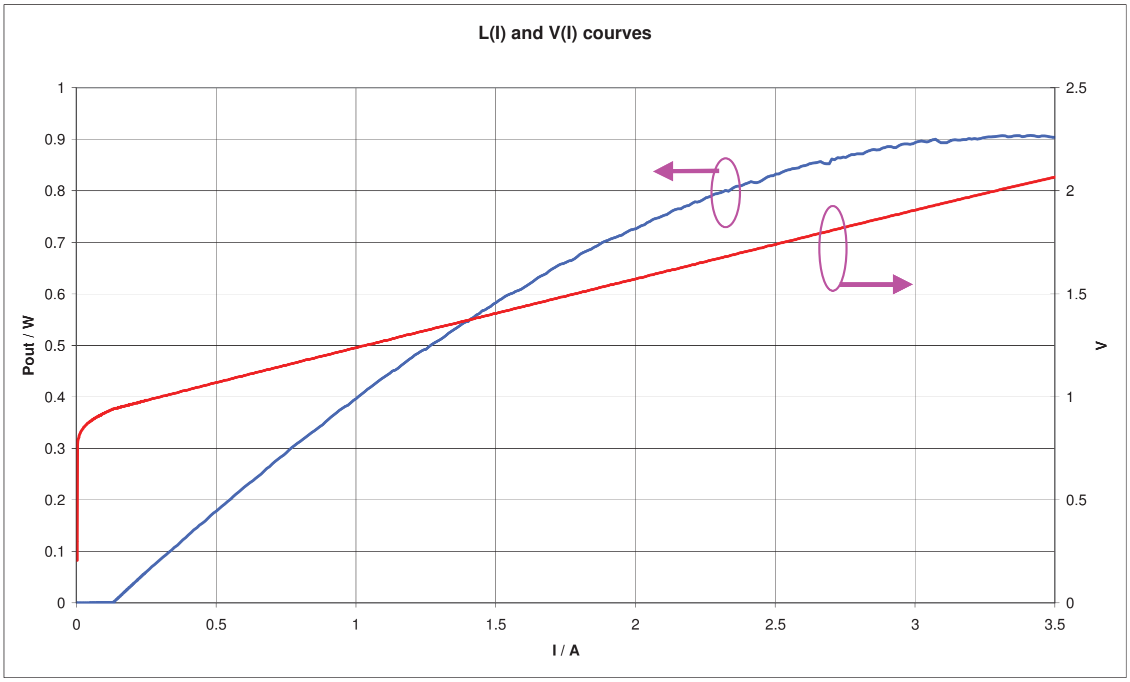

Figure 6. L(I) and V(I) curves @ 25°C.

The presence of the asymmetric cladding allows us not only to achieve low losses; it offers also the possibility to optimize the far field. Indeed, extremely low divergence angles are obtained as shown in the following figure, with a quite symmetric mode of 8° x 14°.

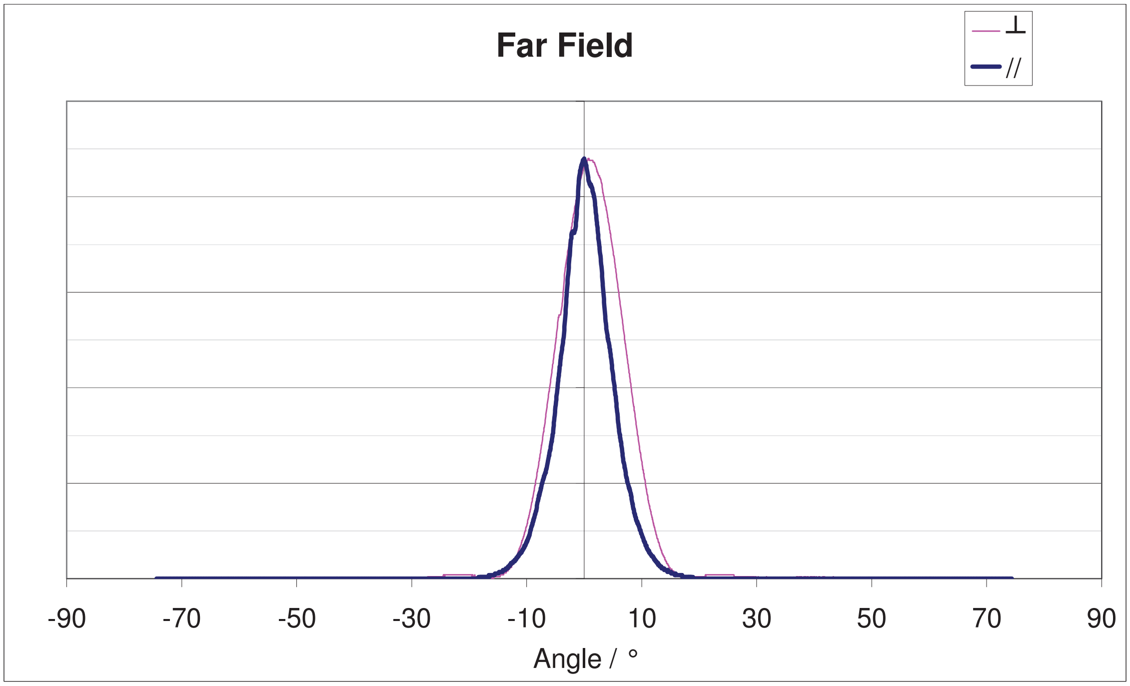

Figure 7. Far field at 1.5 A and 25°C.

All these characteristics show that extremely high performance laser diodes were obtained. These lasers were thus used to realize modules for Raman amplification applications.

2.3. Module design

The lasers are housed in 14-pin low-profile butterfly packages. Fiber Bragg Grating (FBG) are realized in PM fiber. The ensemble is then assembled together with a Peltier cooler. Special care has been taken in the thermal design so as to reduce the thermal resistance of the whole package.

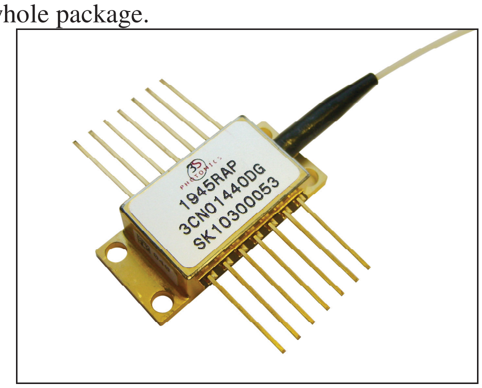

Figure 8. Module picture.

Direct coupling technology is used. After module optimization, a coupling efficiency of 80% is obtained. This is shown on Figure 9. It presents the L(I) curves of a chip on submount (CoS) and of the module housing the same laser diode . The ratio obtained exceeds 80%.

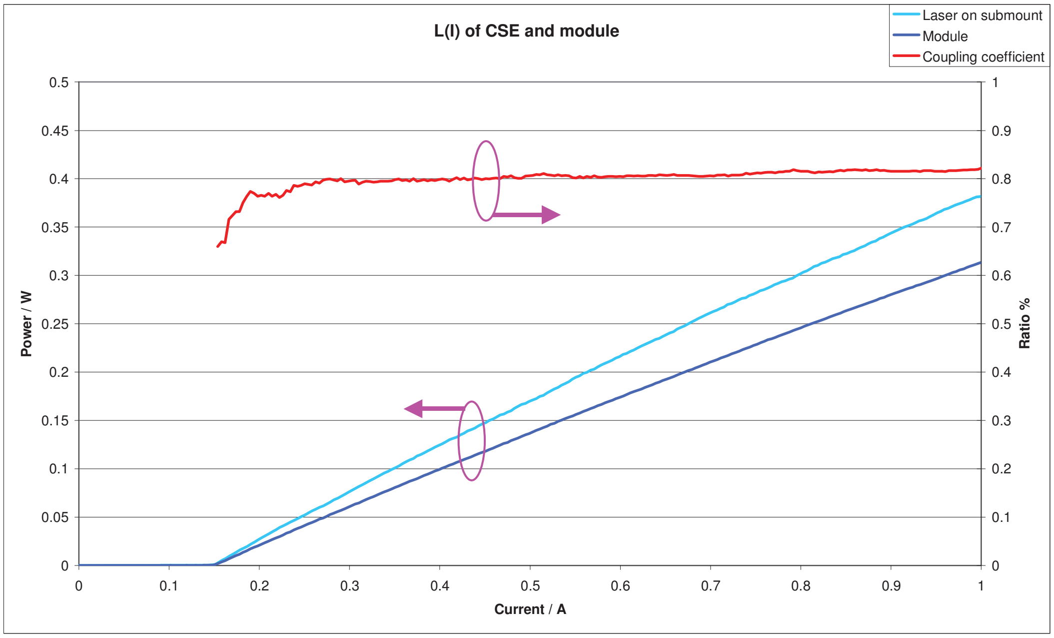

Figure 9. L(I) of CoS and module and computed coupling coefficient.

3. MODULE RESULTS

L(I) and V(I) curves of a typical module with or without FBG are presented in figure 11. As expected, the presence of the FBG reduces the threshold current, but does not affect significantly the output power up to 2A. Output power as high as 700 mW is obtained at 2.5 A, while the current at maximum power is above 3A. The corresponding spectra for output power of 100 mW and 550 mW are presented on the following figures. When the FBG is present, good SMSR is obtained for both low and high power level. Power in band is better than 95 %. These characteristics are fully compatible with requirements for Raman amplification applications.

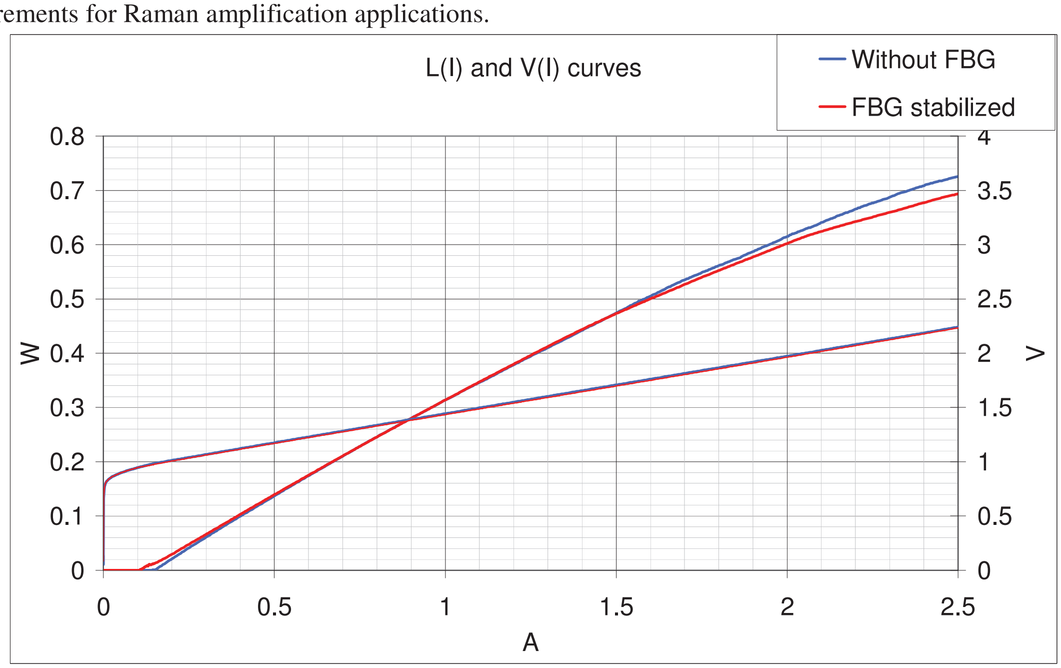

Figure 10. L(I) and V(I) curves with and without FBG.

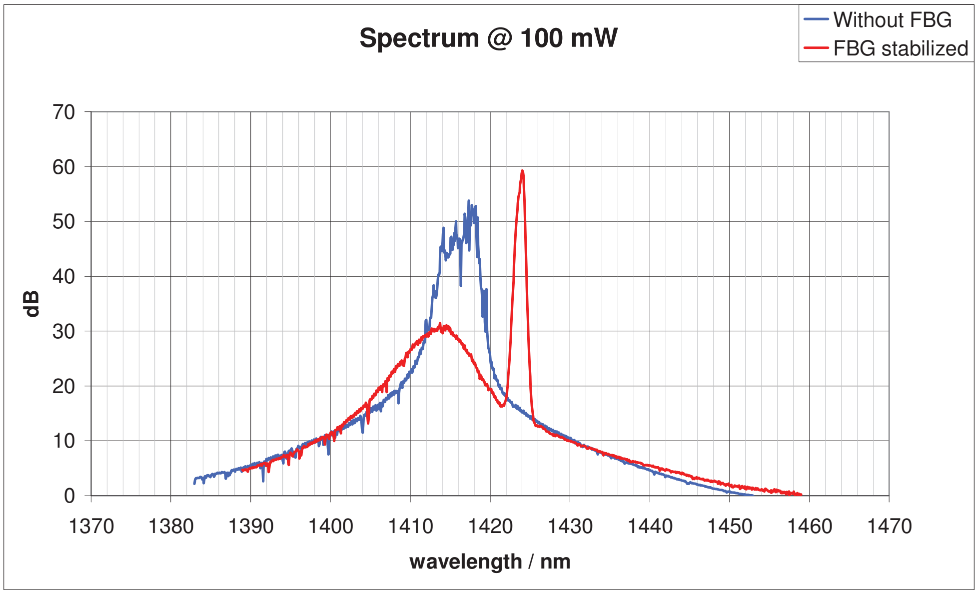

Figure 11. Spectrum at 100 mW.

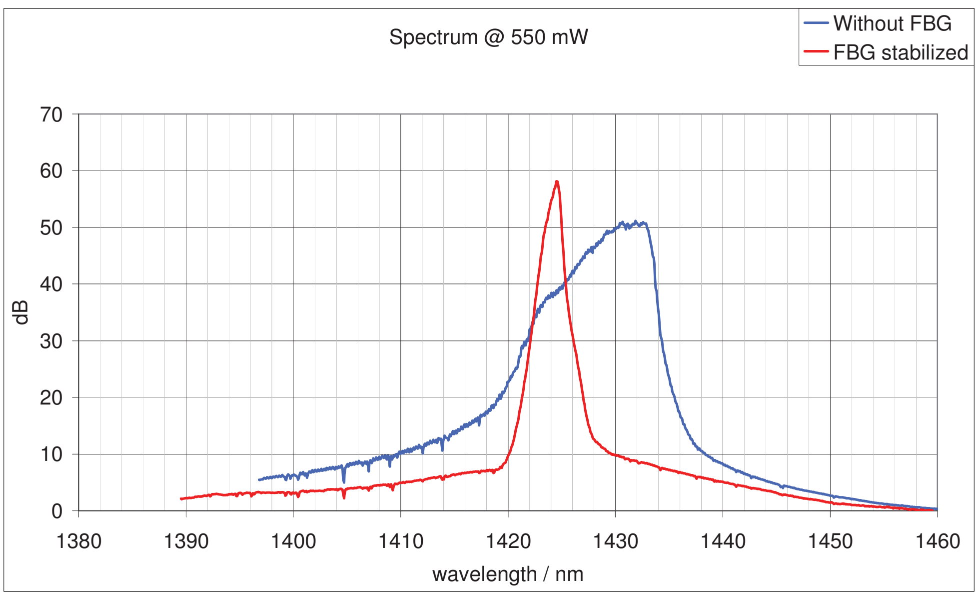

Figure 12. Spectrum at 550 mW.

Finally, the output power must not be obtained at the expenses of an excess of power consumption. Figure 13 presents several curves of consumption versus the case temperature (T_{case}) and for several output powers when the laser diode temperature is maintained at 25°C. P_{Las} is the overall diode consumption (I*V) to reach the desired output power. P_{TEC} is the overall Thermo-Electric Cooler (TEC) consumption (I*V). Finally, P_{total} is the sum of P_{Las} and P_{TEC} and represents the overall module power consumption.

P_{Las} is constant for a given output temperature versus T_{case}. Thanks to the long length of the laser chip, only 3W are needed to obtain 550 mW of outpower.

P_{TEC} is lowest when T_{case} is 25°C. The major increase is for high T_{case} values. Thanks to the optimization of the thermal behavior of the module, a TEC consumption of 6.7 W is required at T_{case} = 75°C and for an output power of 550 mW.

The dual optimization of the laser and module finally allows for a total consumption of 9.9 W to obtain 550 mW at T_{case} = 75°C.

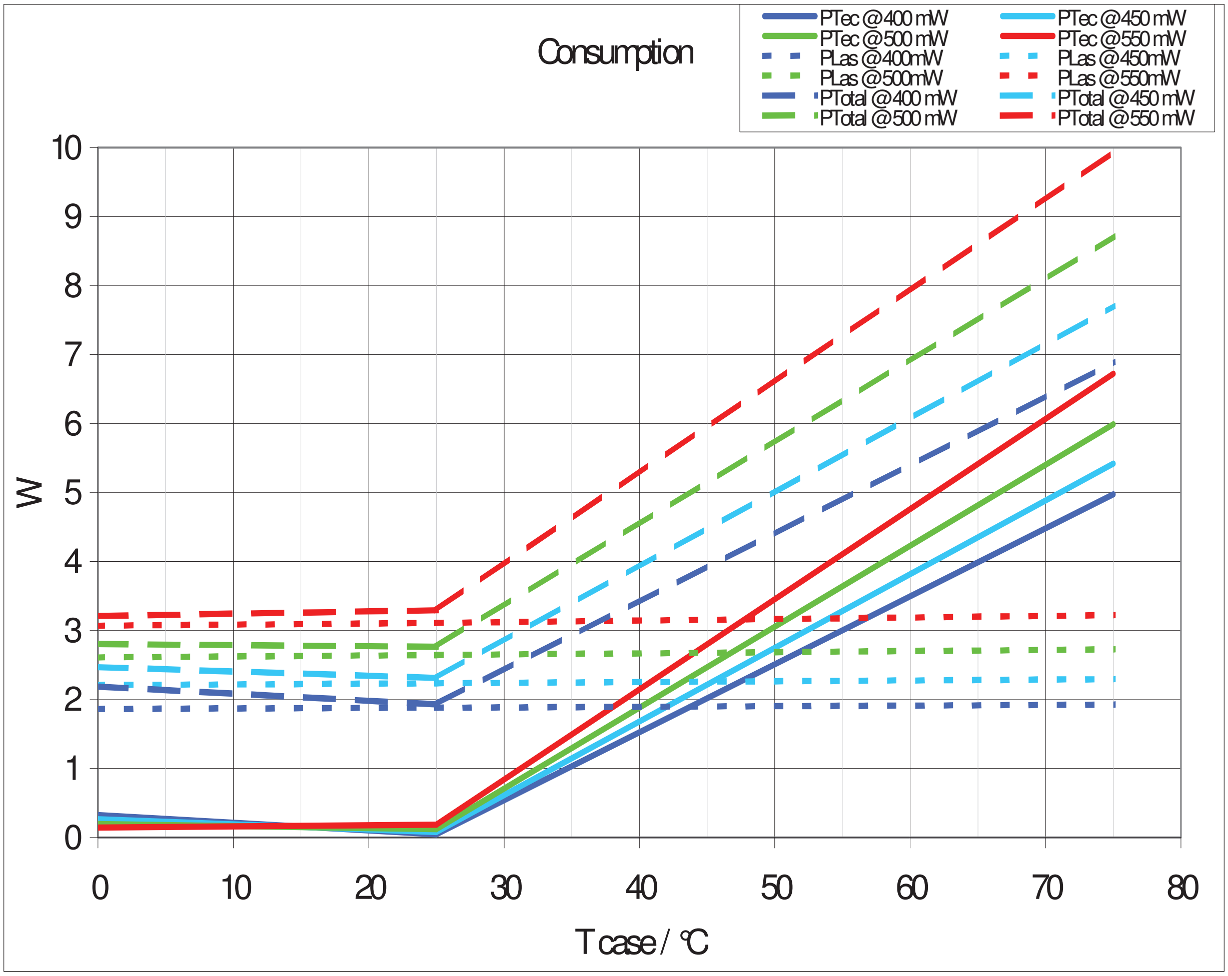

Figure 13. Consumption versus T_{case} for output power values between 400 and 550mW.

4. CONCLUSION

Using the asymmetric waveguide concept, a single-mode laser diode with extremely low losses of 1.5 cm^{-1} and internal efficiency above 0.8 has been obtained, with a nearly symmetric far field of 8°x14°. These features allow for 3 mm laser chips to be developed having 0.9 W of maximum output power on plain AlN submount. A butterfly module has been designed to house this laser chip using direct coupling technology, with special care on the thermal characteristics optimization. These modules show 550 mW output power at 1.8 A, with or without FBG stabilization. The total consumption to obtain this output power is below 10 W at T_{case} = 75°C, one third going to the laser drive and two thirds to the TEC drive.

These laser pump modules break the barrier of high output power Raman pump module and thus open the way to the wide development of Raman amplification in future Optical Networks at very high bit-rate (40 Gb/s and 100GEthernet).

5. ACKNOWLEDGEMENTS

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