INSTITUTE OF ELECTRONIC MATERIALS TECHNOLOGY

133 Wólczyńska Str., 01-919 Warsaw / Poland

Tel.: +48 22 834 90 03; Fax: +48 22 864 54 96

http://www.itme.edu.pl

Increasing of attainable optical power from laser diodes by asymmetric heterostructure design modification.

One of the fields of activity developed in the Institute of Electronic Materials and Technology is semiconductor lasers design, technology and characterization. Current interest is put on medium and high-power laser diodes emitting in 6xx, 800 – 1000 nm wavelength ranges, manufactured basing on (InGaAl)P, (AlGa)AsP and (InAlGa)As material groups, however other wavelength ranges and materials groups can be also of interest. Design, epitaxial growth, wafer processing, mounting as well as materials and device characterizations are developed.

The aim of the proposed project is to increase the maximum optical power attainable from the laser diodes (LDs) by increasing the effective thickness of their heterostructure waveguide. Applications of such modified LDs and LD arrays include optical pumping systems and industrial applications in 8xx or 9xx wavelength ranges. Another parameter decisive for the total power attainable from LD, the width of the emitting area at the laser facet (W - defined by stripe width) can be designed separately, depending on predicted applications.

Increasing the effective thickness of the heterostructure waveguide (d_{eff}) is identical with widening of the optical field distribution outside the active layer (quantum well - QW), perpendicular to the junction plane. For a given catastrophic optical damage (COD) threshold density p_{COD} determined by heterostructure material [1] and operation conditions, the emitted power limit is

$$P_{el} = p_{COD}\, d_{eff}\,, \quad \text{where} \quad d_{eff} = d/\Gamma_0, \qquad (1)$$

where d is the QW thickness and Γ_0 is the QW confinement factor of the fundamental transverse mode.

Such widening of the optical field distribution perpendicular to the junction plane causes an increase of the QW distance from the heterostructure surface and a heatsink in conventional symmetric heterostructures. Increased thickness of cladding and waveguide layers at the p-side gives rise to increased both electrical (R_{th}) and thermal (R_s) resistances as well as to free-carrier loss (α_i) increase due to deeper optical field penetration into doped p-cladding. This results in a decrease of power conversion efficiency (PCE) of LDs.

The proposed solution to this problem is an asymmetric hetero-structure design, as shown in Fig. 1 for the 810 nm range. The idea is to shift the optical field distribution toward the n-side, where a free-carrier loss is 2 – 3 times lower than at the p-side (at the same carrier concentration). Additionally, the n-cladding impurity concentration can be lowered due to higher carrier mobility.

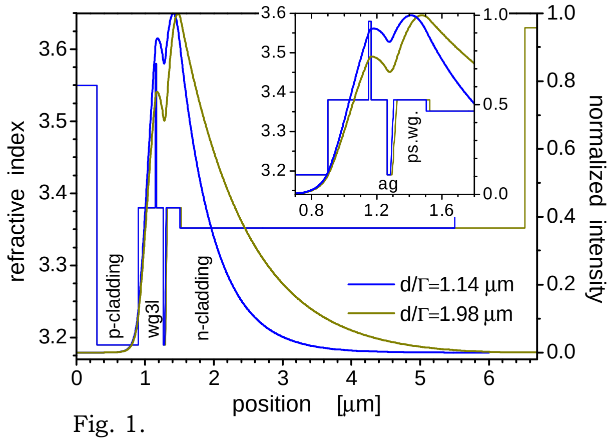


Fig. 1.

The shifted optical field is widened at the n-side and compressed at the p-side. This allows for considerable p-cladding layer thinning, which should result in reduction of both resistances. The thin, high-Al-content barrier layer between the active and passive waveguides (ag in the inset in Fig. 1) has a great influence on the field distribution, allowing for wide degree of freedom in the design of emission characteristics of DL. It is expected that shifting the maximum of the field distribution to the passive waveguide is another way to COD level increase.

Simultaneously, the asymmetry of the field distribution in the waveguide has not a negative, from application viewpoint, consequence for directional characteristics. According to calculations, these characteristics are symmetrical, gaussian-like (Fig. 2), and of low beam divergence, thanks to very wide slope of the field distribution at the n-side. This has been confirmed in so-far experimental results.

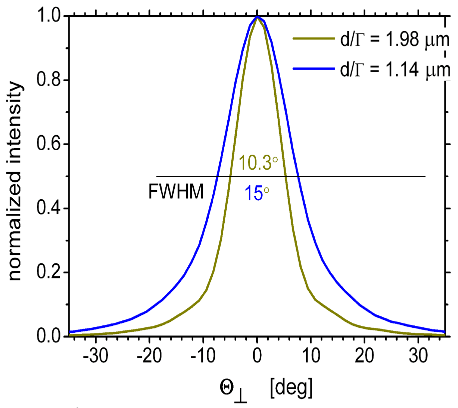
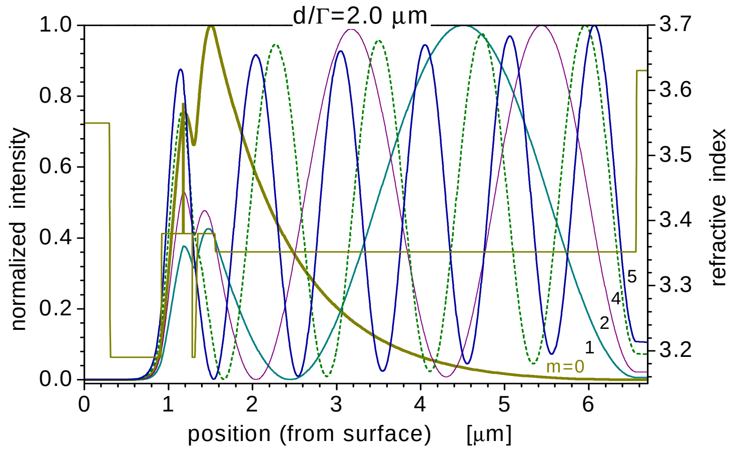


Fig. 2.

The d_{eff} parameter of present-day high power LDs is of the order of 1 µm [2, 3]. The aim of this project is to increase this parameter to about 2 – 3 µm at 810 or 980 nm wavelength range. This should increase attainable optical power output at least two times with respect to present ones at constant W [2]. The predictable difficulties are the necessity of laser cavity length (L) increase, which causes external quantum efficiency decrease and makes handling and mounting issues much more difficult. Next problem is an increase of confinement factors of higher transverse modes (Γ_1, Γ_2, … Γ_m) with d_{eff} increase. This is exemplarily shown in Fig. 3 for modeled heterostructure with $d_{eff} = d/\Gamma_0$ of 2 µm, where Γ_4 and Γ_5 values are higher than half Γ_0. During the project the proper doping profile and possibly some additional layers selectively inserted for quenching high order transverse modes will have to be find.



$\Gamma_0 = 0.00750$ $\Theta_\perp = 10.3°$
$d/\Gamma = 2.0$ µm

$\Gamma_1 = 0.00203$
$\Gamma_2 = 0.00256$
$\Gamma_3 = 0.00286$
$\Gamma_4 = 0.00309$
$\Gamma_5 = 0.00314$
$\Gamma_6 = 0.00281$
$\Gamma_7 = 0.00202$

Fig. 3.

The realization of proposed device will be supported by MOVPE technique for epitaxial growth of heterostructures. Epi-Lab at ITME has been developed as an innovative and progressive initiative to contribute to research activity within the Institute of Electronic Materials Technology situated in Warsaw, Poland. Lab employs top notch specialists in the field of III-V and IV-IV semiconductor epitaxy, combining tradition and experience with modern knowledge and technology. Apart from manufacturing as well as developing low volume advanced research structures, we are actively engaged in commercial activity. One SiC Chemical Vapour Deposition and three Metal Organic Chemical Vapour Deposition (MOCVD) facilities owned by our company enable the production and supply of exceptionally high quality GaAs-, InP-, GaN- and SiC- related epitaxial stacks used either for tests or device purposes, which include F-P lasers and VCSELs. Both basic and advanced characterization methods such as optical, microscopic and electrical method, x-ray and particle scattering are regularly applied by our personnel. Epi-Lab is also eager to participate in long-term research programs. The studies on the growth of proposed laser structure as well as full characterization of obtained material is planned within the project. The technology development will be verified by functional test devices and by final lasers. Research connected to the characterization of epi-structures and device processing will be also carry out in collaboration with Bilkent University ion Ankara.

[1] D. Botez, "High power, Al-free diode lasers", Compound Semiconductors, 5 (6), July/August 1999, 24 – 29.

[2] J. Petrescu-Prahova et al., "253 mW/mm Maximum Power Density from 9xx nm
Epitaxial Laser Structures with d/G Greater than 1 μm", The 21st IEEE Int. Semicond. Laser Conf. (ISLC'2008), 14-18.09.2008, CD, art.WA3.

[3] A. Knauer et al.: High-power 808 nm lasers with a super-large optical cavity, Semiconductor Sci. Technol., 20, No.6 (2005), pp. 621-624.

Contact:
Andrzej Maląg - tel. +48 22 -835 30 41 ext. 104
E-mail: amalag@itme.edu.pl

Włodzimierz Strupiński – tel. +48 22 – 835 30 41 ext. 436;
E-mail: wlodek.strupinski@itme.edu.pl