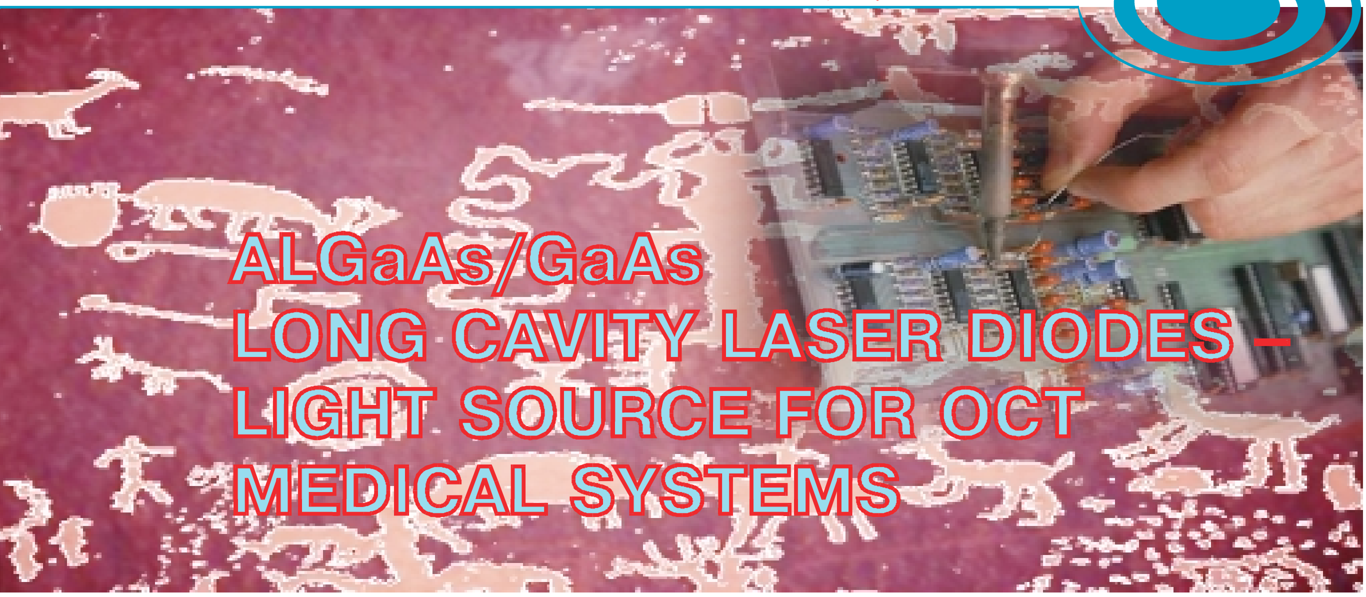


ALGaAs/GaAs LONG CAVITY LASER DIODES – LIGHT SOURCE FOR OCT MEDICAL SYSTEMS

INTRODUCTION

One of the new modern technique for *non-invasive in-vivo* investigations of biological tissues is a optical coherence tomography (OCT) system [1,2]. The suitable optical source for such systems is low coherence (l_c<20 mm) superluminiscent diode (SLD) which allow to perform high resolution medical investigations. Nevertheless, the OCT images looks fragmented due to the low coherence length of the source, and such images is difficult to interpret. Recently was reported a method for images quality improving , using a source with adjustable coherence length [3]. But in spite of performances improving this synthesised source have a limitation due to the coherence function peaks repetition no more than 2 mm. When we have to study a biological tissues with largest thickness, this small repetition interval caused the false images. In order to avoid this inconvenient fact the long cavity laser diode

(LCLD) both with SLD is proposed to utilise in OCT systems. In this paper we demonstrate, that using the new design of synthesised optical source – LCLD together with SLD, we can to increase the performances of OCT medical diagnostic systems for in-vivo biological tissues investigations.

1. COHERENCE MEASUREMENTS EXPERIMENTAL SET-UP

For LCLD coherence characteristics investigations and availability of such light source for OCT applications the modified experimental arrangement based on fiberised Michelson interferometer [5] was used (Fig.1).

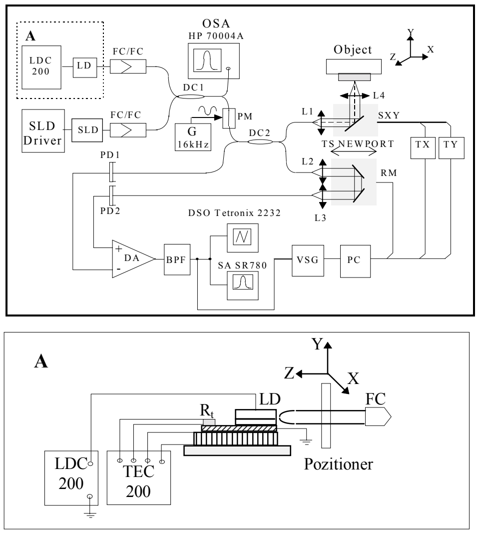
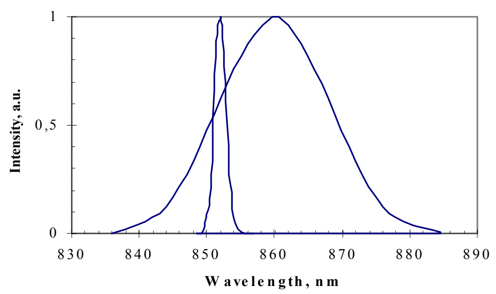
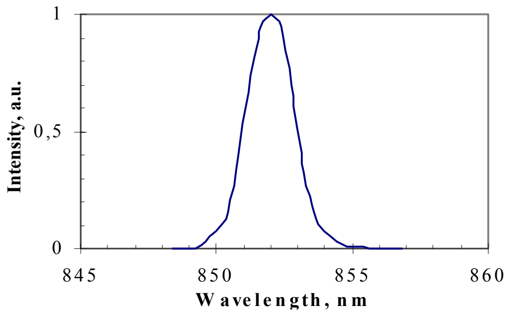


Figure 1. ***Experimental set-up for laser diodes coherence investigations.***

The basic source for this system is a low-coherence single mode fibre pigtailed SLD module with central emission wavelength 860 nm, spectral bandwidth 18 nm and output optical power 5 mW (Fig.2a). The SLD was connected to OCT link via directional coupler DC1. Another input of DC 1 was used for lansing in system of optical power generated by LCLD with emission wavelength around 853 nm (Fig 2b). For recording of LCLD and SLD emission spectra the optical spectrum analyser HP70004A, connected to OCT link via DC 1,as well, was used. Preliminary adjustment of zero optical path balance (OPB) of the OCT system was performed using only SLD as light source then the SLD was switched and LCLD was connected. In presented experimental set-up the real investigated object was replaced with high reflectivity metallic surface.



a)



b)

Figure 2. ***Normalised emission spectra of LCLD+SLD (a) and LCLD ($I_{pumping}$=144 mA) (b)***

2. LASER DIODES STRUCTURE

In this work the graded index separate confinement quantum well buried heterostructure AlGaAs/GaAs laser diodes (GRIN SC QW BH LD) and single mode fibre pigtailed laser diode module (LDM) was used as well. Laser diode structures were grown by low temperature liquid phase epitaxy (LPE) methods in the temperature range 650-400 ^{0}C [8]. Mesa formation was done by in-situ meltetching at 580^{o}C followed by regrowth of AlGaAs reverse p-n junction isolating layers at 580 ¸ 450^{o}C. This method allows etching and preservation of sidewalls then regrowth and planarization all in one step with negligible thermal disordering in quantum wells. Mesa formation in the LPE regrowth process by in-situ melt-etching excludes any oxidation of the etched mesa surface and provides a high quality lateral confining interface. It was shown [8] , that melt-etched mesa shapes depend by: AlAs content x in Al_xGa_{1-x} As cladding layers, stripe orientation and mask adhesivness to the initial epitaxial structure. Have been established that with SiO_2 mask and x=0.2¸0.5, there is a strong anisotropy of melt-etch rate, while with $x \geq 0.6$ in the similar processes melt-etching material selectivity becomes the most important factor of mesa shaping. The best results of using SiO_2 masking for in-situ meltback and regrowth are obtained when meltback undercutting is almost as much as the meltback etching depth.

Thus using these results of LPE regrowth technique a GRIN SC QW BH LD with emission wavelength around 853 nm have been fabricated. A scanning electron micrograph of the cleaved cross section of such structure is shown in Fig. 3 and consists of a 2 µm thick n-GaAs buffer layer, a 1,5 µm thick n-$Al_{0,7}Ga_{0,3}As$ widegap emitter, 0,15 µm n- $Al_{0,6-0,3}Ga_{0,4-0,7}As$ GRIN waveguide, 20 nm n - $Al_{0,08}Ga_{0,92}As$ active , 0,15 µm n-$Al_{0,3-0,6}Ga_{0,7-0,4}As$ GRIN waveguide, 1 µm thick p- $Al_{0,7}Ga_{0,3}As$ widegap emitter and a 0,2 µm p^+ GaAs cap layer. The buried heterostructure was formed in the second LPE process by melt etching of the laser structure part not protected by SiO_2 stripes (typical width 6-7 µm), followed by p^+-and n- $Al_{0,4}Ga_{0,6}As$ regrowth to provide lateral electrical and optical confinement.

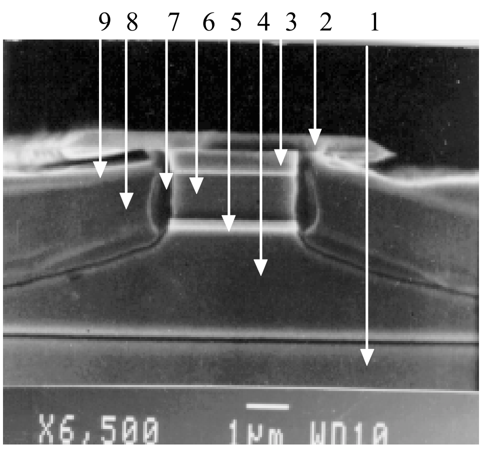


Figure 3. ***Scanning electron micrograph of the cross-section of melt-etched and regrowth AlGaAs/GaAs buried heterostructure.***

1-n-GaAs buffer layer. 2-SiO_2 stripe. 3-GaAs cap layer. 4-n-$Al_{0.7}Ga_{0.3}As$ widegap emitter.
5- $Al_{0,6-0,3+0.6}Ga_{0,4-0,7+0.4}As$ GRIN waveguide and quantum well $Al_{0.03}$ $Ga_{0.97}As$ active region.
6-p-$Al_{0.7}Ga_{0.3}As$ widegap emitter. 7-boundary of etching in the melt (p-$Al_{0.55}Ga_{0.45}As$).
8-p^+-$Al_{0.4}$ $Ga_{0.6}As$. 9-n- $Al_{0.4}$ $Ga_{0.6}As$.

After standard procedure of Au-Zn, Au-Ge ohmic contact deposition the laser bars with different cavity lengths (500-2700 μm) was cleaved. The LD chips was "p-side down" mounted on the Cu heatsink.

3. RESULTS AND DISCUSSIONS

The LD with cavity lengths 580 μm, 1600 μm, 1900 μm and 2700 μm and stripe width w=7 μm have been studied. The cavity length of laser diode crystal mounted inside of pigtailed module was 500 mm.

For coupling of investigated LD with single mode fibre (5,5 μm /125 μm) the Newport positioner was used (Fig 1 bloc A). The fibre end had hemispherical microlens and another one was spliced with FC-type connector. The devices was temperature controlled using the 5,3 W thermoelectric cooler (TEC) MELCOR and TEC driver TED 200. The coherence function envelope data and coherence repetition peaks was collected using electrical signal analyser SR 780 and suitable electronic scheme. Have been established that the dependence of coherence peaks repetition via cavity lengths for samples S724 is linear and is shown in Fig. 4. Calculated refractive index from this dependence is n=3.52 and is in suitable agreement with normally accounted (n=3.42) value for $Al_{0.3}Ga_{0.7}As$ (waveguide layer) semiconductor compound [9]. After coherence measurements of all LD chips we have study more rigorously the sample with cavity length L=1900μm. The value of threshold current was 115 mA and measured optical output power from single mode fiber (5,5/125 μm) supplied by such LCLD was 0.6 mW at 144 mA. For this sample the coherence function envelopes via different level of pumping currents are presented in Fig.5. The values of coherence length l_c vary from 195 μm to 360 μm for pumping currents between 119 mA and 144 mA respectively and is in good agreement with equation: [6]

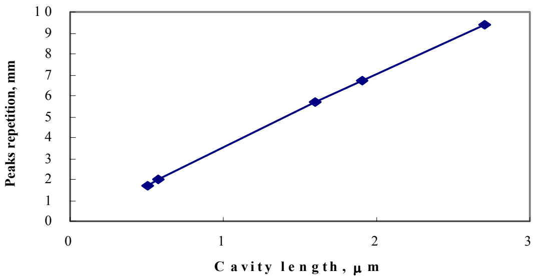


Figure 4. ***Coherence function peaks repetition via cavity lengths for GRIN SC BH LD (S724).***

$$l_c = \frac{4 \ln 2}{\pi} \frac{\lambda^2}{\Delta\lambda} \qquad (1)$$

where λ - central emission wavelength
Δλ - spectral bandwidth

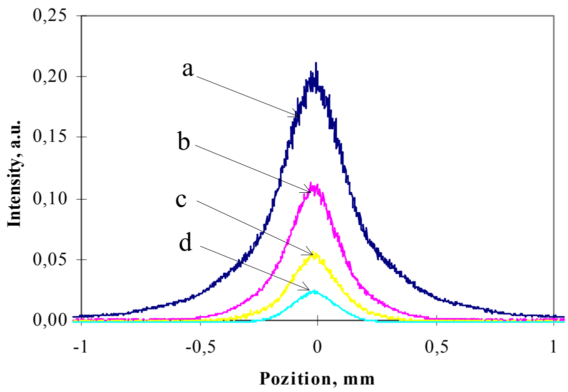


Figure 5. ***Coherence function envelope of the sample S724 (L=1.9mm) for different values of pumping current: a) I_p=144 mA (l_c=361μm); b) I_p=137 mA (l_c=250μm); c) I_p=129 mA (l_c=222μm); d) I_p=114 mA (l_c=195μm).***

These values of l_c means that the depth sectioning interval using LCLD may vary from 97,5 μm to 180 μm.

For this range of currents, the power in fiber supplied by LCLD increase from 0,13 to 0,6 mW. The distance between main coherence function peaks is 6,8 mm (Fig. 6).

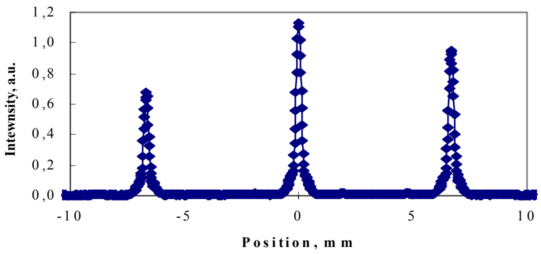


Figure 6. ***Coherence function peaks repetition of the sample S724 (L=1,9 mm), I_p=144 mA.***

Is important to mention the absence of secondary peaks(up to -80 dB) between the main coherence maximum. This fact allow to expect the successful investigation and images acquisition of the object with about 6 mm thickness, instead of the maximum 2 mm when the three electrode laser was used as light source in OCT system [3,7].

In order to investigate the performances of such light source for medical OCT applications a different images of the cancerous skin sample have been acquired . The amplitude of sawtooth voltages applied to the two galvanometer scanners ensure a span about 6x6mm over the skin surface. The three OCT images are taken for different positions of the translation stage, i.e. for different penetration depths. In Fig. 7 we present the OCT images collected at 100 mm depth in the skin. The first image was collected using the SLD as light source. The power of SLD was attenuated up to 0.6 mW. The OCT images taken with the SLD look fragmented, only parts of the cancerous skin are displayed. The second image was collected using only the LCLD on the maximum coherence length. This image show a larger region of the skin and is easy to detect the cancerous metastases in the tissue. The fragmented aspect characteristically for first image disappears. The last image was collected when SLD and LCLD operate concomitantly. The concomitantly operating of the SLD and LCLD allow first to select and investigate more rigorously some regions of the investigated object (in our case the cancerous metastases).

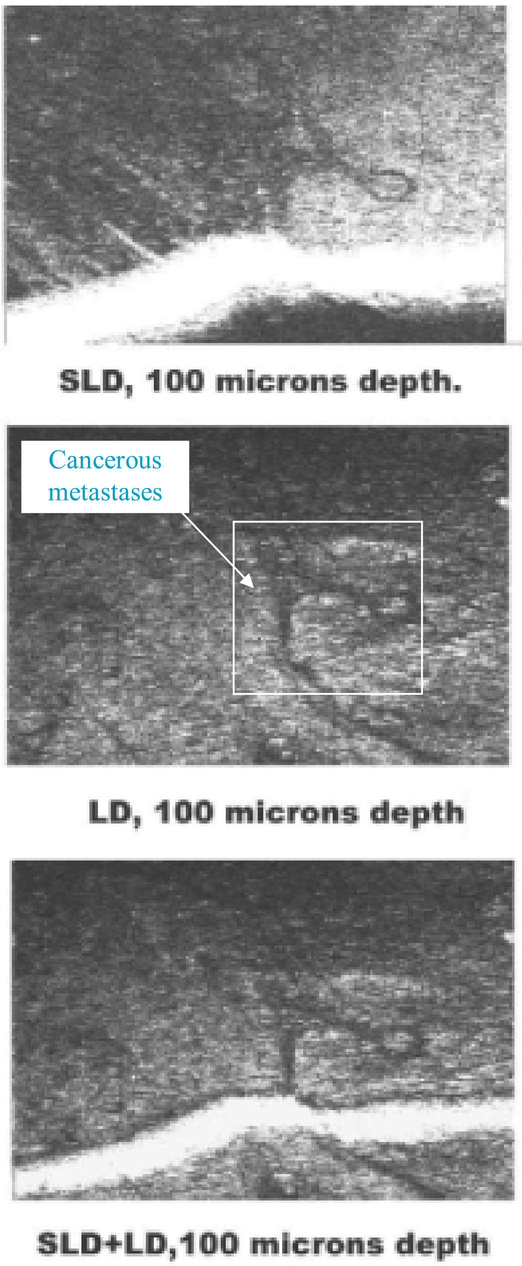


Figure 7. ***The OCT images of the cancerous skin sample at the 100 mm depth from the surface.***

CONCLUSIONS

In conclusions we underline that using of the LCLD as light source in optical coherence interferometry systems allow to increase the coherence function peaks repetition more than

2 mm - the limit for industrial fabricated semiconductor lasers, and thus to improve the performances of OCT systems. Using of such sources together with SLD allow to collect the OCT images which could be easy interpreted by medical specialists.

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Diode laser AlGaAs/GaAs cu cavitate lungă – sursă de lumină pentru sistemele medicale OCT

REZUMAT

În lucrare sunt prezentate rezultatele cercetărilor asupra realizării unei construcţii de tip nou a unei surse sintetizate de lumină pentru sistemele medicinale de tomografie de coerenţă optică (OCT). Sursa este constituită dintr-o diodă laser AlGaAs/GaAs cu cavitate lungă (LCLD) şi o diodă superluminiscentă (SLD). Lungimea de undă de emisie a LCLD este foarte aproape de cea a SLD-ului. Lungimea de coerenţă a emisiei dispozitivului LCLD atinge valoarea de 195 mm vizavi de 20 mm pentru SLD-ul standard. A fost stabilit că variind lungimea cavitaţii diodelor laser AlGaAs/GaAs este posibilă mărirea distanţei dintre maximurile funcţiei de coerenţă până la valoarea de 6,8 mm. Acest fapt permite de a efectua investigaţii prin metoda de tomografie de coerenţă optică a ţesuturilor biologice cu grosimea mai mare de 2 mm - mărime maximă in cazul aplicării diodelor laser de producţie industrială.

Sunt prezentate imaginile OCT a unei regiuni din ţesut pielos colectate cu ajutorul sursei sintetizate.

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