Dynamic Fine spectroscopy of Heterolaser Radiation Change under an Alternating Strain

L.A. Kulakova

A.F. Ioffe Physicotechnical Institute of RAS St Petersburg 194021,Russia

E -mail: L.Kulakova@mail.ioffe.ru

Overview

Recently [1, 2] we have fulfilled the pioneer study of the heterolaser frequency tuning by ultrasound strain. Such way make it possible to realize very precise frequency tuning (in the range up to several hundred GHz) at constant level of the emission intensity.

To optimize the interaction parameters it was necessary to develop some universal and mobile technique of fine spectral analysis of a laser emission.

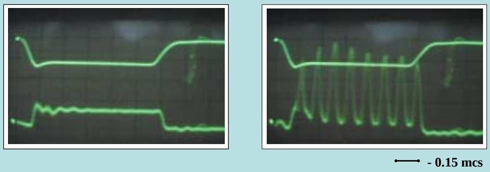
The advantages of the dynamic method for fine spectrum study of heterolaser emission and of its change under ultrasonic strain are shown. The model of fine dynamic spectrum analysis has been designed and the treatment of experimental data on spectrum dynamics of the InGaAsP/InP-structures at the presence of surface acoustic waves has been carried out. Thus the appreciable contribution of the acousto-optic interaction (comparable with the acousto-electron one), resulting in the modulation in time of the positions of the heterolaser optical resonator lines was found out. The second not less important result is the opportunity of calculation of the lagging in phase of acousto-optic and acousto-electron interactions. **In the studied** ***structures they are in phase so the sound introduction leads to the synchronous modulation of the spectral positions, both the laser curve line, and lines of the laser resonator with periodicity of the sound wave.***

Results and Discussions

To visualize the anticipated modulation of the laser emission frequency by the ultrasound, we used the wide-band detection channel after FPE. The results for surface waves are presented in Fig. 5.

Fig.5. Oscillograms. The upper sweep represents the operating current pulse (33 mA/div), the lower - laser radiation pulses.

a), a sound is off **b), sound (F = 10 MHz) is on**



To optimize the interaction parameters it was necessary to develop some universal and mobile technique of fine spectral analysis of a laser emission.

For the first time we have investigated an untraditional case, when the sound wave $S = S_0 \sin(\Omega t - Qx)$, propagates across a thin semiconductor layer representing an optical resonator (Fig.1), that means: $a \ll L_S$,

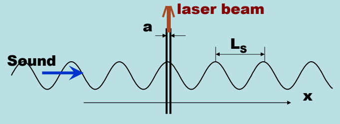


Fig.1

So due to acousto-optic interaction a refractive index change in time with periodicity of acoustic wave

$$\Delta n \approx pS_o Sin\Omega t \qquad (5)$$

Band gap E_g is also changed in time in the same way due to acousto-electron interaction

$$\Delta E_g \approx \Lambda S_o Sin\Omega t \qquad (6)$$

These effects may result in change of generation conditions, and so change of laser spectral parameters: a) the spectral positions of the laser resonator lines and b) the gain curve spectral position.

Methods

Object for the study: InGaAsP/InP laser heterostructures operating at T=300K in the pulsed regime, duration up to 3mcs, at a wave-length of 1.48mcm. The operating current I_{op} = (1 - 3) I_{th}

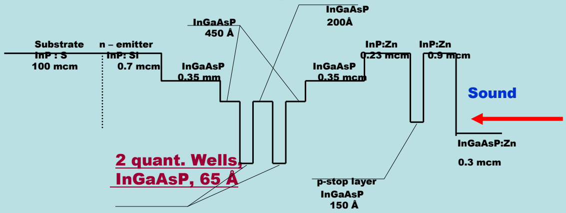
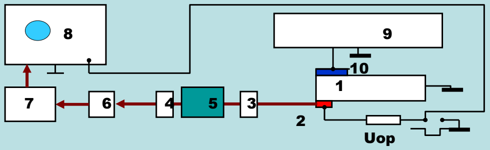


Fig.2. The laser heterostructures of separate confinement with two strained quantum wells : schematic space-energy bandgap diagram

Fig. 3. A schematic diagram of the experimental setup: (*1*) metal substrate (sound line); (*2*) laser heterostructure; (*3*,*4*) focusing lenses; (*5*) Fabry–Perot etalon; (*6*) photodiode; (*7*) amplifier; (*8*) oscilloscope; (*9*) microwave oscillator; (*10*) piezoelectric transducer.



Radiation detection

1. Direct detection, 2. after a Fabry–Perot etalon (FPE); 3. registration by optic monochromator in pulse regime.

To generate alternate elastic strain the bulk and surface ultrasonic waves were excited in the frequency range of (5 – 15) MHz, using piezoelectric resonator plates (10) and interdigital transducers (Fig. 4).

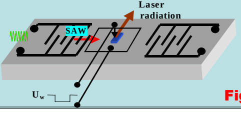


Fig.4

Acknowledgments

The large gratitude to my colleagues from the Ioffe Physico-Technical Institute RAS (Prof.Tarasov I.S. and his employees) for high quality laser structures, and for useful discussions.

Presidium of RAS and RFBR (Grant № 07-02-00557) for Financial support

References

1. L.A. Kulakova, A.V. Lyutetskiy, N.A. Pikhtin, I.S. Tarasov and E.Z. Yakhkind, “Acousto-electron interaction in InGaAsP/InP laser heterostructures,” Ultrasonics 44, e1535- e1540 (2006).

L.A. Kulakova, N.A. Pikhtin, S.O. Slipchenko, I.S. Tarasov, “Controlling the Radiation Spectrum of Quantum-Well Heterostructure Lasers by Ultrasonic Strain,” J. Exp. Theor. Phys.104, 689-695 (2007).

Because the the spectral distribution study by a monochromator is very laborious more preferable, in our opinion, may be the dynamic spectral analyses by a Fabry–Perot etalon (FPE).

Recall that a F-P resonator has maxima of transparency for a monochromatic collimated beam when interference conditions are realized. Different orders of transparency are determined by a resonator length L_0:

$$\frac{2L_0}{\lambda^k} = k ,$$

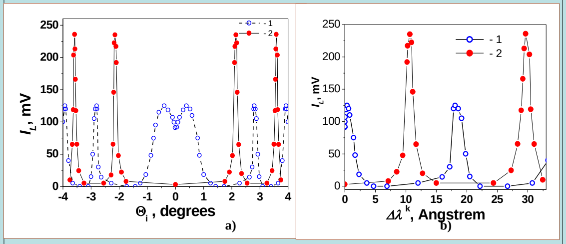
or the incidence angle θ_i , $L = L_0 / Cos\theta_i$. At $\theta_i \ll 1$, k = const.

$$\Delta\lambda^k = \lambda^k \theta_i^2 / 2$$

So varying the incidence angle we can fulfill fine spectral analysis (Fig.6) within of the angular dynamic dispersion range:

$$\theta_{in} = \pm\sqrt{n\lambda^k / L_0}$$

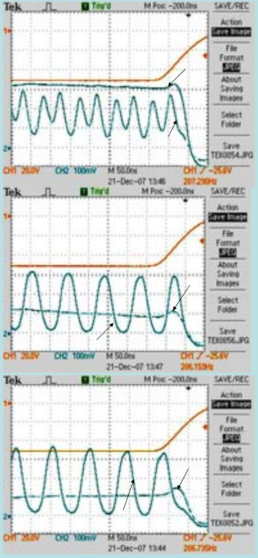
Fig.7. Experimental dispersion curves of FPE at single mode laser emission: 1 - *Iop*= 1.4 *Ith*, 2 - *Iop* = 1.6 *Ith*



We can see the symmetric picture a) concerning normal incidence (θ_i =0) of light.

Fig.9. Oscillograms the intensity light modulation after FPE at different position $\Delta\lambda^1$ around central line of 1th-order resonance:

Experiment, **Theory:** $1 - L_e = 0,\ L_R = 0;\ 2 - L_e = 1.2\ \mathring{A},\ L_R = 1\ \mathring{A};\ 3 - L_e = 1.2\ \mathring{A},\ L_R = -1\ \mathring{A}$



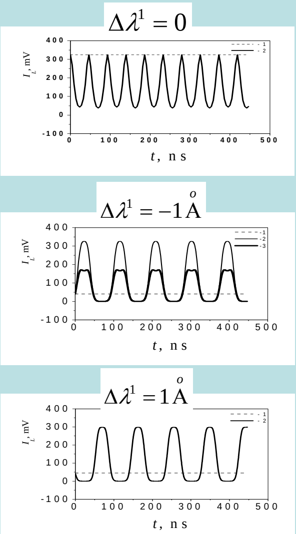
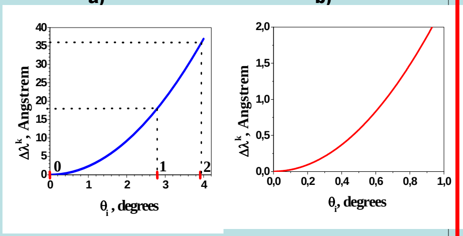


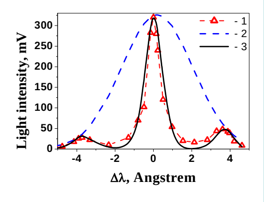
Fig.6. $\Delta\lambda^k = \lambda^k \theta_i^2 / 2$, $L_0 = 0.6mm, \lambda^k = 1.48\mu m$

a) **b)**



At rotation of FPE around zero angle position it is possible to carry out the fine analysis of a radiation spectrum accurate within tenth fractions of Å.

Fig.8. The spectral distribution of the laser intensity around central line of 1th-order resonance (I_{op} = 1.7 I_{th})



1 – experiment, 2, 3 - theory: 2 - gain curve - $I_e(\Delta\lambda)$ **, 3 -** $I(\Delta\lambda) = I_R(\Delta\lambda) * I_e(\Delta\lambda)$

$$I_e(\Delta\lambda, t) = I_0 + A\exp\left(-\frac{2(\Delta\lambda - \Delta\lambda_m + L_e Sin\Omega t)^2}{w_e^2}\right)$$

$$I_R(\Delta\lambda, t) = \sum_q \exp\left(-\frac{2(\Delta\lambda - q\Delta\lambda_R + L_R Sin\Omega t)^2}{w_R^2}\right)$$

I_e: $I_0 = 1mV,\ A = 325mV,\ \Delta\lambda_m = 0.2\mathring{A},\ w = 3.71\mathring{A},$

I_R: $q = -1,\ 0,\ 1,\ \Delta\lambda_R = 3.9\mathring{A},\ w_R = 0.9\ \mathring{A}$

SUMMARY

Results of the dynamic spectral analysis can be formulated as follows.

The width of the laser resonator lines ≈1Å.

Sound introduction leads to the spectral position modulations, both the laser gain curve, and lines of the laser resonator with periodicity of the sound wave.

The observed picture agrees well with the calculation results within the framework of the suggested model at commensurable modulation amplitudes of the resonator lines (L_R = 1 Å) and the laser gain curve (L_e = 1.2 Å) spectral positions at the strain amplitude value near 10^{-5} (10 MHz SAW frequency).

At the same time it has been established the synchronous modulation of the spectral positions, both the laser curve line, and lines of the laser resonator with periodicity of the sound wave. It implies the opportunity of continuous and fast tuning of the emission frequency in the range of 27 GHz during a sound wave period.

Increase of the strain value (with increase of the SAW frequency) makes it possible to increase the tuning range up to the order of the value that means up to 270 GHz