**InAsSb/InAsSbP heterostructure lasers with a large range of current tuning of the lasing frequency**

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The lasing spectra and the shift in the position of the modes in the current range \((1−5)I_{th}\) with various methods of pumping the nonequilibrium charge carriers are analyzed. It is shown that the pumping method does not influence the character of the tuning of the radiation line. The large short-wavelength tuning range up to 50 Å is due not to the heating of the crystal lattice in the active-region material but rather the nonuniform nonequilibrium charge-carrier density distribution over the width of the stripe. © 1999 American Institute of Physics.

1. An important element of superhigh-resolution diode laser spectrometers is a frequency-tunable fast-response diode semiconductor laser. In previous work, we reported instantaneous, smooth current tuning of the lasing frequency of InAsSb/InAsSbP heterostructure diode lasers emitting near 3.3 μm.1–7 It was found that smooth tuning of the lasing frequency of a diode laser is possible by varying the current in the range of longer and shorter wavelengths, which occurs at a rate higher than the thermal-relaxation rate.1 In Ref. 6, a change in the radiation wavelength by 15 Å in the single-mode lasing regime, i.e., in a regime where the intensity of the predominant mode is greater than the total intensity of all other modes, was obtained in InAsSb/InAsSbP laser structures. Wavelength tuning by 30 Å into the short-wavelength region in structures with a small stripe width (10 μm) in a single-mode regime with a total shift of a single mode by 55 Å was reported in Ref. 4.

Our objective in the present work is to obtain a wider range of wavelength tuning of laser radiation in the single-mode lasing regime and to determine the effect of the method used to pump nonequilibrium charge carriers on the tuning process. For this, lasers with a larger strip width than in Ref. 4 were investigated.

2. We studied laser diodes based on the double heterostructures \(N\cdot\text{InAsSb}_{0.17}\text{P}_{0.35}/n\cdot\text{InAsSb}_{0.05}\text{P}/P\cdot\text{InAsSb}_{0.17}\text{P}_{0.35}\), obtained by liquid-phase epitaxy on a \(p\)-InAs substrate with hole density \((5−8)\cdot10^{18} \text{ cm}^{-3}\). The active region was 1 μm thick, and the wide-gap emitters were 3 μm thick. The active region was not specially doped. The electron density in it was \(10^{16} \text{ cm}^{-3}\). The \(N\)-InAsSbP layer was doped with Sn to electron density of about \(1\cdot10^{18} \text{ cm}^{-3}\), and the \(P\)-InAsSbP layer was doped with Zn to density \((2−5)\cdot10^{18} \text{ cm}^{-3}\). The arrangement of the layers and the energy diagram of the diode structures are shown in Fig. 1.

Mesostrips with a width of 16 μm were formed by photolithography on the structures grown. Fabry–Perot cavities of length 250–375 μm were obtained by cleaving. The laser was 500 μm wide in the region of the substrate, and the substrate was about 100 μm thick.

The investigations were performed at liquid-nitrogen temperature using various methods for pumping the nonequilibrium charge carriers: in the cw regime with the laser powered by short current pulses with 0.04 ms and a duty factor of 100, saw-tooth pulses with a repetition frequency from \(10^2\) to \(10^4\) Hz, and alternating square pulses with a duty factor of 2 and a 36 Hz repetition frequency.

The spectral composition of the radiation obtained with different methods of pumping and with different pump currents ranging from the threshold value \(I_{th}\) up to \(5I_{th}\) was...
studied on the diode laser structures. When the laser was powered by saw-tooth current pulses, the shift of the radiation mode was measured using a Fabry–Perot cavity.

3. The radiation spectrum of laser diodes near the lasing threshold with various pumping methods is displayed in Fig. 2. One mode is present with all currents irrespective of the pumping method. For currents of about $3I_{th}$, shorter wavelength modes appear, making up to 10% of the contribution to the total intensity of the radiation. As the pump current increases from $3I_{th}$ to $5I_{th}$, the intensity of the short-wavelength modes increases more strongly than the intensity of the previously observed mode, and for $I > 3.5I_{th}$ the intensity of the previously predominating mode is less than the sum of the intensities of all other modes. The regime is no longer a single-mode regime.

As the current increased further, the mode shifted smoothly into the short-wavelength region. For currents near $3.5I_{th}$, the change in wavelength with current slows down, and the spectrum is no longer a single-mode spectrum. The total short-wavelength shift of the initial radiation mode in the one-mode regime in the current range ($1.8-3.5)I_{th}$ was $42 \text{ Å}$, i.e., 40% greater than in Ref. 4. In the current range ($3.5-4.5)I_{th}$ this mode shifted by another $8 \text{ Å}$. The total shift of the mode was $50 \text{ Å}$. In this series of samples the shift into the short-wavelength region of the spectrum occurred within the entire intermode spacing. Measurements of the radiation spectra using various methods to power the laser did not show any differences in character and magnitude of the change in the radiation wavelength with current. This shows that the crystal lattice of the active-region material is not heated when the laser structure is powered by different methods.

In summary, the experimental results obtained indicate that the substantial short-wavelength tuning of the lasing wavelength is due to not heating but rather radiation generation processes.

4. The initial increase in the radiation wavelength with current increasing to $1.8I_{th}$ has already been attributed to self-focusing of the radiation with uniform injection. For currents near $1.8I_{th}$ the differential resistance of the $p-n$ junc-