Reduction of the Threshold Temperature Sensitivity of 1.55 µm InGaAsP Lasers by Subnanosecond Optical Excitation

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Abstract. InGaAsP lasers operating at 1.5 to 1.6 µm were pumped optically with a pulsed 1.06 µm source. The temperature dependence of the pump energy at laser threshold has been measured for temperatures from 170 to 330 K. Pump pulse widths of 300 ns and 150–300 ps were employed, long and short compared to the carrier life-time in the laser material. Over the high-temperature range of 260 to 330 K short pulse excitation gives a considerable reduction of the threshold temperature sensitivity with a characteristic temperature \( T_0 = 85 \) K compared to \( T_0 = 45 \) K for long-pulse excitation. This is in qualitative agreement with previous results on electrically excited lasers although the temperature sensitivity of the optically excited lasers is larger. At temperatures between 170 to 260 K no reduction of the temperature sensitivity was observed.

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The threshold current of InGaAsP injection lasers has been found to increase rapidly with temperature \( T \). Over a certain temperature range the threshold current depends on temperature \( T \) as \( \exp(T/T_0) \) with a characteristic temperature \( T_0 \) ranging from 100 K at low temperatures to 50 K at room temperature. This behaviour is unfavorable for applications in fiber-optic communications systems and therefore a large number of investigations has been performed in order to understand and improve the performance of these lasers. Most of the work up to now has been devoted to lasers emitting at 1.3 µm. Investigations \([1-5]\) of the threshold temperature dependence of lasers for the 1.5 to 1.6 µm region are comparatively scarce although the technological importance of these lasers may become even larger because of the lower fiber loss in this spectral region. The aim of the present paper is to contribute to the explanation of the long-wavelength laser behavior and to demonstrate a method to improve the unfavorable temperature sensitivity.

The basic idea of the experiments to be described has been applied previously to the 1.3 µm laser \([6]\) and consists in using short optical or electrical pulses for laser excitation. A similar investigation has also been performed with a 1.5 µm laser and electrical excitation \([5]\), the temperature range was 280 to 350 K. In the subsequent paper laser-threshold investigations are extended down to 170 K using optical excitation as a different experimental method.

If the excitation pulse width is short compared to the carrier life-time of 1–5 ns \([9]\), the excited carrier density \( n \) is given simply by the total number of injected carriers. In contrast with cw or long-pulse excitation, the carrier density depends also on the life-time. Comparing short and long pulse excitation it is thus possible to separate mechanisms causing the threshold temperature dependence. For lasers emitting at 1.5–1.6 µm, this temperature dependence has been attributed to a decrease of the carrier life-time, e.g. by Auger recombination \([1-4]\), and to intervalence band absorption \([1,3,4]\) increasing with temperature at laser threshold. Using short-pulse excitation the contribution of the decreasing carrier life-time to the temperature dependence can be eliminated. The remaining threshold temperature dependence has to be explained by other mechanisms, e.g., the temperature dependence of the gain and/or intervalence band absorption.
Experiment

The InGaAsP lasers were optically pumped by pulses from a Nd-YAG laser with a wavelength of 1.06 μm. The advantages of optical compared to electrical excitation for material investigations have been discussed earlier [6]. The optically pumped lasers are easily fabricated from InGaAsP layers by cleaving. Undoped active and buffer layers can be employed since pn junctions are not required. Therefore, optical pumping is very convenient for material testing. A possible drawback is the high excess energy of the optically excited electrons which may cause carrier heating as will be discussed later.

The InGaAsP lasers were cleaved from three different wafers. The thickness of the active layers ranged from 0.43 to 0.75 μm, the laser wavelength 300 K from 1.5 to 1.6 μm. The active layers imbedded in different buffer and cap layers were grown by LPE on InP substrates polished to 150 μm thickness.

The cw Nd-YAG pump laser was operated either Q-switched, producing long pulses with 300 ns width and 1 kHz repetition frequency, or mode locked. To reduce the average power of the mode-locked pump laser and to avoid heating of the sample, two methods were employed. First, the cw-mode-locked laser beam (150 ps pulse-width and 10 ns distance) was mechanically chopped resulting in bursts of pulses with a width of 500 ns and a repetition frequency of 1 kHz. Second, in order to obtain a larger time separation of the ps pulses, an acousto-optic dumper was used to increase the pulse period to 400 ns. To compensate for the low diffraction efficiency of the dumper, the mode-locked laser was simultaneously Q-switched using a technique described in [7]. Thereby the pulse width increased to 300 ps. Q-switching produced bursts of these pulses with a width of 2 μs and a distance of 25 μs.

The beam of the Nd-YAG laser was focused onto the InGaAsP sample by cylindrical lenses so that a laser stripe of about 50 μm width was excited. Luminescence and laser action was observed with a germanium diode shielded by a 1 cm silicon filter to block scattered 1.06 μm excitation radiation. The InGaAsP laser threshold was characterized by the onset of strong amplitude fluctuations of the diode signal. The fluctuations indicate the highly nonlinear increase of the laser output power at threshold enhancing the slight fluctuations of the pump laser.

Experimental Results

The measured peak power at threshold $P_{th}$ for long-pulse excitation and the threshold carrier density $n_{th}$ for short-pulse excitation are shown in Fig. 1 for different samples, temperatures and excitation pulse widths. The dependence of $P_{th}$ on sample temperature agrees qualitatively with the threshold current temperature dependence of electrical injection lasers [1–4]. The $n_{th}$ values for the different samples are displaced so that the absolute values should not be compared. The carrier density $n_{th}$ was assumed to be directly proportional to the incident pulse energy. The temperature dependence of the absorption has not been taken into account. It is estimated that this effect would decrease the measured $T_0$ values by less than 10%.

The $n_{th}$ values given for excitation by the 150 ps pulses with 10 ns repetition time have been corrected to take into account the pile-up of the carrier density due to the incomplete carrier decay between two pulses. For the correction, the carrier life-time data at laser threshold given in [9] have been used. For the 1.50 μm sample, $n_{th}$ values were obtained both with excitation with 150 ps pulses and 10 ns repetition time, and 300 ps pulse bursts with 400 ns repetition time. Both measurements give the same results within the experimental accuracy proving the validity of the correction procedure.

In Fig. 1, in addition, straight line fits to the experimental data are shown. The slopes of these lines give the $T_0$ values in the respective temperature regions. The temperature dependence of $n_{th}$ can be described by