# Analysis of the major loss processes in mid-infrared type-II "W" diode lasers.

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The results from high-pressure and low-temperature measurements on mid-infrared type-II W-structure lasers suggest that Auger recombination is the major loss process that prevents their continuous-wave operation at room temperature.

The development of semiconductor lasers for the 2 - 5 µm spectral region is motivated in part by proposed applications in medicine and trace gas detection [1]. In the 3 - 4 µm range, type II "W" structure lasers display very good performance in comparison to competing material systems. However, the challenge of achieving room temperature (RT), continuous-wave (CW) lasers throughout this wavelength range still remains [2,3]. The lasers studied here emit at 3.24 µm (@ 78 K) and contain 5 W-periods, each comprising of a Ga(In)Sb hole quantum well (QW) surrounded by two InAs electron QWs, all enclosed between AlGa(As)Sb barrier layers. Spontaneous emission analysis and hydrostatic pressure techniques have been used to examine the primary loss mechanisms which inhibit the RT, CW performance of these W-lasers.

Analysis of the unamplified spontaneous emission emitted from a window milled into the substrate contact of the lasers was carried out at a range of temperatures from 80K to 180K to investigate radiative and non-radiative processes. An example of a spontaneous emission versus current curve at 80 K is shown in fig. 1. The linear section of the L-I curve in fig. 1 indicates that over this section, much of the injected current is recombining radiatively. However, the fact that the linear section does not go though the origin implies that there is some defect/impurity-related recombination, which is important at low current. This component remains small even at higher temperatures.

Above 50 mA we see a strongly sub-linear variation indicating the presence of a non-radiative current path such as Auger recombination which is known to be a problem at these long wavelengths [4].

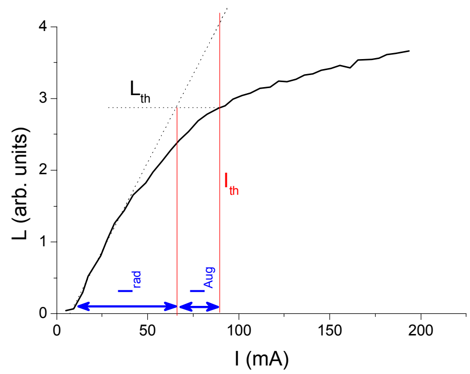


**Figure 1** – Spontaneous emission light intensity versus current at 80 K.

This sub-linearity of the light-current curve becomes more severe with increasing temperature, consistent with Auger recombination being the primary cause of performance degradation at higher temperatures. If we estimate the radiative and non-radiative contributions to the threshold current ($I_{th}$) as shown in fig. 1 and take the proportional change in the light level at threshold ($L_{th}$) with temperature, we can determine the temperature dependence of the radiative and hence non-radiative contributions to the threshold current over the temperature range, as shown in fig. 2. Here we see that the non-radiative component of the threshold current increases from approximately 34% at 80K, where $J_{th}$ is 65 $Acm^{-2}$, to about 88% at 180K, where $J_{th}$ is 895 $Acm^{-2}$, mainly due to an increase in Auger recombination. It should be noted that the $I_{rad}$ values plotted in fig. 2 remain consistent with the values of the radiative current deduced from the linear section in fig. 1 when the temperature is changed.

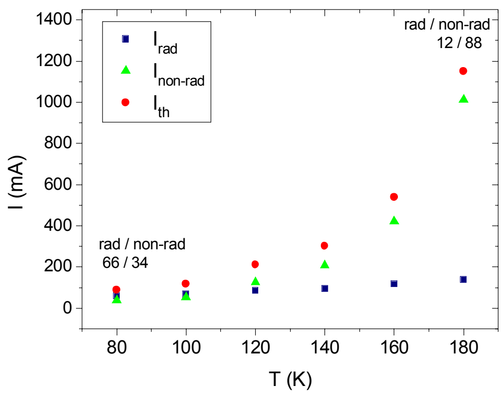


**Figure 2** – Radiative (squares) and non-radiative (triangles) contributions to the threshold current (circles).

The application of hydrostatic pressure to a semiconductor laser is another useful tool to determine the important loss processes in a device. In III-V semiconductors the application of pressure causes an increase in the fundamental band gap, $E_g$, and hence allows the study of band gap dependent processes. The measured wavelength shift with pressure of these devices yielded a pressure coefficient of the band gap of 8.7 meV/kbar, which is in excellent agreement with the results of an 8-band k·p calculation.

Figure 3 shows the pressure dependence of $I_{th}$ at 105 K, 125 K and 138 K. Initially a decrease in threshold current with pressure is observed for all temperatures. In telecommunications wavelength lasers, which are dominated by Auger processes that generate hot holes, a decrease in threshold current with pressure (band gap) is observed, as the Auger coefficient C is reduced [5]. The W-lasers studied here have a complex valence sub-band structure at hole energies close to the band gap, and the excitation of a hot hole by Auger processes could explain the measured pressure dependence.

The initial decrease in threshold current could be explained by one Auger process moving out of resonance, while as pressure (band gap) is increased further, another hole-exciting Auger process approaches resonance. Additionally, this complex valence sub-band structure could give rise to inter-valence-band absorption (IVBA) which could also move in and out of resonance with pressure. More detailed band structure analysis is now needed.

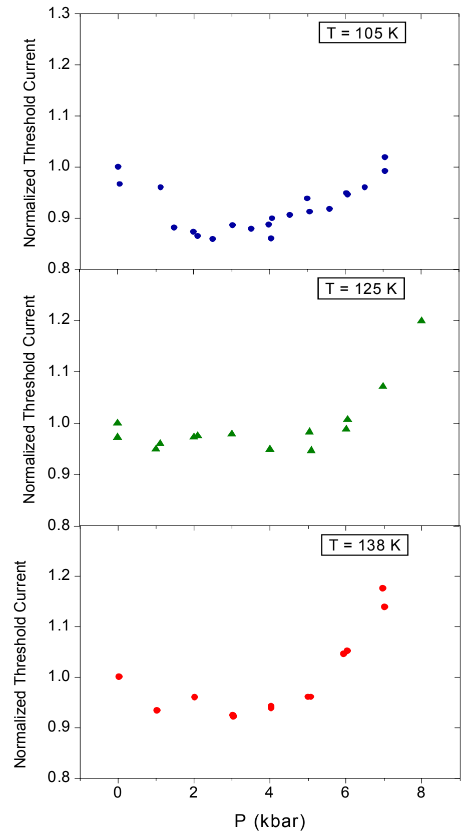


**Figure 3** – Pressure dependence of the threshold current of a W-laser at several temperatures.

In conclusion, we have observed a strong loss process which increases with increasing current, characteristic of Auger recombination. IVBA may also be contributing to the temperature dependence as will be discussed further at the conference. Finally, understanding of the complex valence sub-band structure and control of the hole concentration may be a key issue to be addressed in these devices.

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