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Blue Lasers and the Quantum Confined Stark Effect in II-VI Strained Quantum Wells

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Quantum well ZnSe laser structures have been fabricated using iodine and nitrogen as n- and p-type dopants, respectively. Our studies of the ZnSe:N material show that it is not possible to increase the active acceptor concentration by growth with UV and optically detected magnetic resonance shows that there is a new anisotropic deep donor signal which is consistent with our proposal that the compensation is due to a centre such as the V_{Se}-Zn-N_{Se} single donor. The quantum confined Stark effect in p-i-n structures has been investigated and the first self-electro optic effect device (SEED) operating in the blue has been demonstrated.

At Heriot-Watt we have fabricated ZnSe laser diodes by molecular beam epitaxy using an electrochemical iodine cell for the n-type doping and a nitrogen plasma source for the p-type doping.[1)] The iodine is an excellent dopant up to concentrations of $10^{19}cm^{-3}$. Typically three or four quantum wells of $Zn_xCd_{1-x}Se$ are used with x ≈ 0.15 - 0.2 and well widths of 50-100Å giving laser emission as short as 472nm at low temperatures as shown in Figure 1.

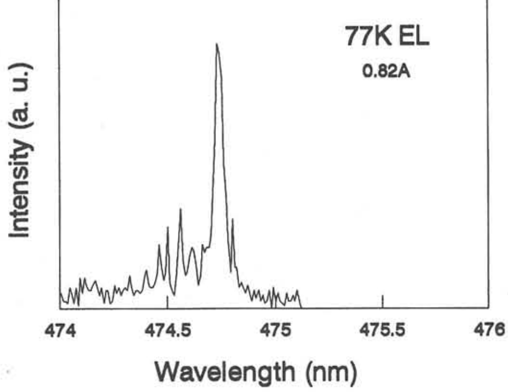


Fig. 1 Laser emission at 77k just at threshold.

The development of II-VI blue lasers is currently limited by the contact to the p-layer which, in most cases, is ZnSe or lattice matched ZnSSe. There are two main approaches to solve this problem which results in threshold and operating voltages as high as 25V. The first is to find a high work function metal to replace the gold or gold-platinum contacts. Haase et al[2)] report a search of elements without success and so an alternative approach of fabricating p-type heterostructure contacts has been pursued. For example, Fan et al[3)] have used digital ZnSeTe alloy contacts and Yang et al[4)] have explored HgTe contacts which has allowed the p-type ZnSe to be measured by the Hall effect. The second approach has been to attempt to increase the hole concentration by increasing the active nitrogen acceptor concentration and it has been this approach that we have taken at Heriot-Watt.

Qiu et al[5)] were the first to show that the active nitrogen acceptor concentration is limited in ZnSe to approximately $10^{18}cm^{-3}$ due to the formation of compensating donors which are related to the nitrogen concentration and the growth temperature. As the nitrogen concentration is increased the compensation increases to a level such that the material becomes insulating. Similarly, lowering the substrate temperature, particularly by the use of cracked selenium where growth temperatures can be lowered to ~150°C, maximises the value of (N_A-N_D).

We have investigated the compensation process by growing ZnSe:N epitaxial layers with illumination of UV radiation from a krypton ion laser. The UV has two effects on the ZnSe. Firstly, the growth rate decreases and, in fact, can be brought to zero when the film is approximately 150nm thick.[6] Also the UV results in the incorporation of the nitrogen increasing over the unilluminated layers by a factor of approximately 5x as assessed by the optical spectra. However, unfortunately the number of active nitrogen acceptors does not increase and, in fact, the action of the UV at the growth surface is to suppress the incorporation of selenium and so is equivalent to reducing the Se:Zn flux ratio which is known to enhance nitrogen incorporation.[7]

A detailed optical study of the nitrogen material has also been carried out and two donor-acceptor recombination paths have been identified, one associated with a shallow donor and nitrogen acceptor and the other with a deep donor and nitrogen acceptor.[8] The identity of the deep donor has been deduced from changes in the electrochemical C-V profiles of ZnSe:N material with time and the defect has been associated with a selenium vacancy - nitrogen acceptor pair (V_{Se}-Zn-N_{Se}) which is a single donor. Recently, we have examined these recombination processes with optically detected magnetic resonance which allows one to examine the resonance spectra of the defects involved in recombination processes. Figure 2 shows spectra from ZnSe:N samples showing shallow and deep donor recombination. A new anisotropic deep donor signal has been observed at g=1.38 as well as a g=2 acceptor signal. The results are consistent with our proposed model.

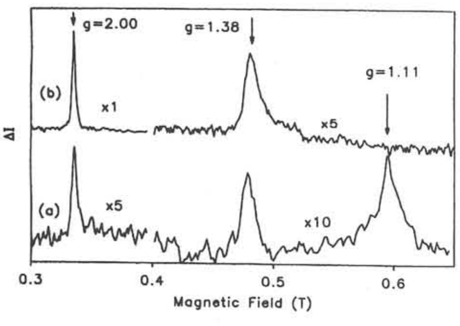


Fig. 2. ZnSe:N ODMR
(a) Emission showing shallow and deep donors
(b) Deep donor and acceptors

As part of our optical studies of laser structures we have examined a series of undoped quantum well structures by excimer-dye laser optical pumping. In particular, we have performed the first excitation spectroscopy of the laser emission in order to explore the lasing mechanism.[8] Figure (3) shows the results for a 30A quantum well at 77K. Monitoring the laser emission as the excitation energy is scanned shows that even at the highest excitation powers the light and heavy exciton absorptions are clearly observed. The red shift of the laser emission in a range of samples with well widths from 15Å to 120Å are all near 30meV which corresponds to the LO phonon energy. Although inhomogeneous broadening is clearly important in these structures, the red shift is independent of the well width and so strong phonon coupling appears to dominate the lasing mechanism.

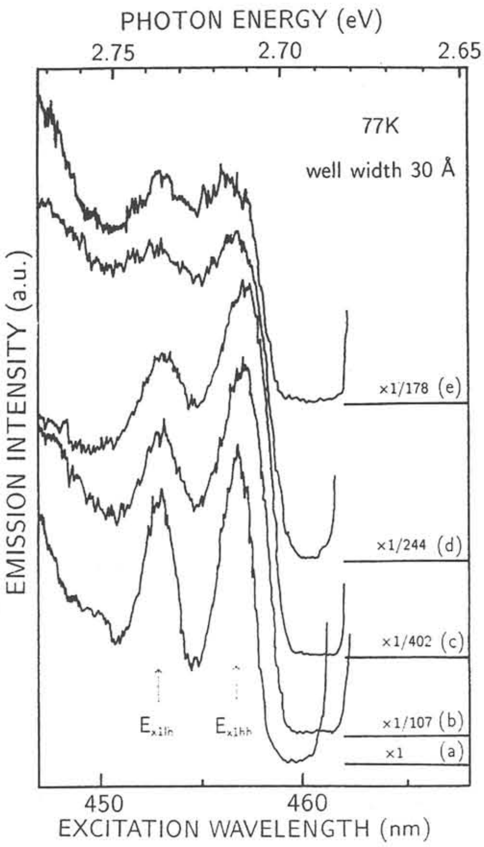
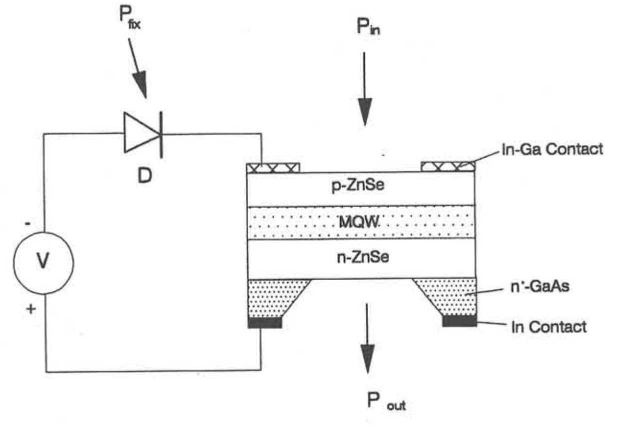


Figure 3. Excitation spectrum for an optically pumped quantum well laser structure

The development of a range of optoelectronic devices for the visible spectrum is important. We have reported the first optical modulators based on the quantum confined Stark effect using p-i-n structures with 20 $Zn_xCd_{1-x}Se$ quantum wells.[10] In reverse bias these devices show ~10% change in transmission. A set of modulator structures with quantum wells of different widths has been investigated and compared with theory. A modulator structure can be configured as an optical bistable switch if reverse bias is applied via a series resistor or photodiode. This results in a self-electro optic effect device or SEED and the two levels of transmission can be assigned to 0 and 1 for optical processing. We have recently demonstrated the first II-VI diode-SEED bistable device and the circuit and switching characteristics are shown in figure 4.[11]



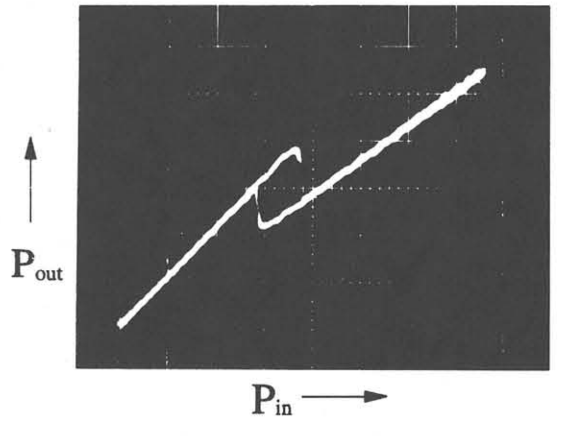


Figure 4. Photodiode bias circuit for a D-SEED optical switch with bistability characteristics

Acknowledgements

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