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Visible Semiconductor Laser

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Visible semiconductor laser has been expected as a key device for optical information processing systems by replacing gas lasers which are bulky, mechanically elaborate, expensive, and require considerable power. Recent development of short wavelength AlGaAs laser is now permiting it to be used practically in applications such as video playback system and laser printer. This paper describes the state of the art visible semiconductor lasers, particularly the AlGaAs laser.

Since the advent of semiconductor laser, substantial effort has been devoted to realize visible laser emission from various kinds of semiconductor materials. The first visible laser emission was obtained from GaAsP homojunction lasers. Wide range of visible laser emission was reported from II-VI binary and ternary compounds by electron beam excitaion. These visible lasers, however, have disadvantages such as high treshold, or, unease of electron excitation apparatus for pumping, and can not operate continuously at room temperature.

After the introduction of AlGaAs homojunction laser grown on closely lattice matched GaAs substrate by LPE, and the following AlGaAs-GaAs heterojunction laser for reducing threshold, the effort has been concentrated to develop visible lasers made of III-V ternary and quarternary direct energy gap compounds, AlGaAs, InGaP, and InGaAsP.

The effort to extend wavelengths of junction lasers to shorter wavelengths has led to the investigation of InGaAsP double heterojunction lasers grown on GaAs P VPE wafers by constant temperature LPE. In the InGaAsP system, the energy gap of the direct-indirect crossover is 2.24 eV, which implies that the lasing wavelength less than 600 nm might be obtained. The shortest wavelength reported at room temperature is 647 nm with threshold current density of $2 \times 10^4 \text{ A/cm}^2$, which is one order higher than that of AlGaAs lasers. This seems to be the poor crystal quality of the double heterostructure layers on the GaAsP available at present time, which is not free from lattice defects and surface irregularities generated by the mismatch dislocations in the compositional grading layer between the GaAs constant layer and the GaAs substrate.

From the practical point of view, AlGaAs junction lasers have been extensively investigated, since last ten years. In the AlGaAs system, the direct-indirect transision occurs at the Al content x = 0.37 and the threshold current density is not changed in the Al content x from 0 to 0.25, which was first confirmed in homo-

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junction lasers. The corresponding wavelength for x = 0.25 is near at 750 nm at room temperature. The threshold current increases with Al content x more than 0.25 rapidly due to thermal excitation of injected electrons into the indirect conduction band with much larger density of states than those of the direct conduction band. The injected electrons in the indirect bands recombine nonradiatively through the interband recombination centers and do not contribute to lasing.

The characteristics and technology of AlGaAs lasers have been made a remarkable progress in the recent past. Several kinds of low threshold, mode stabilized lasers have been developed. The operating life has been drastically improved by growing DH structure in oxigen free ambient to elliminate DSDs, by reducing bonding stress using Si submount, by passivating mirror surface with dielectric films such as SiO_2 , Al_2O_3 , and Si_3N_4 to protect mirror degradation due to oxidation. As a result, single mode operation with MTTF more than 10^6 hr at room temperature has been estimated in TJS lasers with the wavelength arround 850 nm.

The technology has now being applied to develop visible lasers with wavelength shorter than 780 nm. In TJS lasers, it has been confirmed that the threshold current has been almost unchanged for Al content x from 0 to 0.25 or for the wavelength range from 900 to 750 nm, and 20 to 30 mA at 300K. Such low threshold has been achieved in TS lasers for the same wavelength range recently. The shortest wavelength obtained at 300 K is arround 710 nm, which has been confirmed first in CSP lasers with threshold several times higher than those of longer wavelength lasers.

One of the most important problems of short wavelength AlGaAs lasers in practical use was the short operating life. Conventional lasers with the wavelength less than 740 nm degrades within several minutes to several hours only during the passage of current. It has been pointed out that this is caused by tension stress due to the lattice mismatch between the AlGaAs DH layer and the GaAs substrate. The Al content x in the AlGaAs cladding layers of the short wavelength laser exceed 0.6 which leads to the tension stress at the active layer over a critical value of 1 x 10^8 dyne.cm⁻². It has been reported recently that the stress can be reduced by inserting a relatively thick AlGaAs buffer layer (10 µm) between the DH layer and the substrate, which has led to a drastical improvement of the operating life time more than ten thousand hours in HIS lasers.

In conclusions, the characteristics and the operating life of the short wavelength AlGaAs laser have been drastically improved and lasers with a practical wavelength arround 750 nm will be available by replacing bulkier, more fragile gas lasers in many optical information processing applications.