Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 437-439

Self-Sustained Pulsation in 650nm-Band AlGaInP Visible Laser Diodes with Highly Doped Saturable Absorbing Layer

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650nm-band self-sustained-pulsing AlGaInP laser diodes were successfully demonstrated by adopting novel structure, which has highly doped saturable absorbing layer. Short carrier lifetime, which is indispensable for pulsation, was realized by applying high doping concentration to the saturable absorbing layer. 500μm-long devices were fabricated, resulting in the threshold current of 65mA at room temperature. The relative intensity noise (RIN) was below -138dB/Hz in the temperature ranging from 20 to 50°C at 5mW.

1. INTRODUCTION

650nm-band AlGaInP visible laser diodes having very low intensity noise characteristics with self-sustained pulsation of light output were developed for applications such as optical data storage[1-3]. Self-sustained pulsation is effective for the reduction of the noise because of the suppression of mode competition noise in multi-longitudinal mode oscillation. Although the AlGaInP visible laser diodes with self-sustained pulsation was reported before[2,3], stable operation in the high temperature range was very difficult in AlGaInP systems. The reason is that the conventional device uses a saturable absorbing region in the active layer outside the ridge stripe. In this case, the control of the structure parameters such as stripe width and refractive index step difference between the inside of ridge stripe and the outside is very severe for producing laser diodes with stable pulse output[3].

We have employed a saturable absorbing layer in the neighborhood of active layer in order to realize the pulsation. It is possible to grow the thickness of the epitaxial layers accurately by using metalorganic vapor phase epitaxy (MOVPE). As a results, possibility of reproduction becomes high as compared with the conventional pulsing lasers. However, the pulsation phenomena cannot be realized only by adding a saturable absorbing layer to AlGaInP visible laser diodes. We have found that highly doped saturable absorbing layer, in which carrier lifetime was reduced, was effective for realization of the pulsation. We report on stable, self-sustained pulsing of AlGaInP visible laser diodes with low intensity noise characteristics in the temperature ranging from 20 to 50°C.

2. DESIGN

The dynamics of semiconductor lasers with saturable absorbing layer can be described by the following rate equations:

$$\frac{dS}{dt} = [\Gamma_1 g_1(n_1) + \Gamma_2 g_2(n_2, p) - g_{th}]S + \beta_{sp1}\frac{n_1 V_1}{\tau_1(n_1)} + \beta_{sp2}\frac{n_2 V_2}{\tau_2(n_2, p)} \quad (1)$$

$$\frac{dn_1}{dt} = -\frac{\Gamma_1}{V_1} g_1(n_1)S - \frac{n_1}{\tau_1(n_1)} + \frac{I}{eV_1} \quad (2)$$

$$\frac{dn_2}{dt} = -\frac{\Gamma_2}{V_2} g_2(n_2, p)S - \frac{n_2}{\tau_2(n_2, p)} \quad (3)$$

where S is the total photon number, n_1 is the electron density in the active region, and n_2 is that in the saturable absorbing layer. I is the injected current density into the active region, and e is the electron charge. Optical confinement factor, volume of the effective region, and spontaneous emission coefficient are denoted by Γ, V and β_{sp}, respectively. The suffix 1 and 2 denoted in the active region and in the absorbing layer, respectively. The hole doping concentration in the absorbing layer was denoted by p. It is to be noted that in our analysis, the gain g and carrier lifetime τ are functions of the electron density and doping concentration.

In order to realize the self-sustained pulsation, the carrier lifetime in the absorbing layer, τ_2, must be made short to maximize dn_2/dt in equation (3). The value of τ_2 is design-controllable due to its dependence on doping concentration. The dependence was calculated with taking into account a subband mixing in the valence band[4]. Figure 1 shows the relationship between carrier lifetime and optically pumped carrier density in the saturable absorbing layer.

In the case of highly doped ($p=2\times10^{18}cm^{-3}$) layer, the lifetime is shorter than that in the low doped ($p=4\times10^{17}cm^{-3}$) layer. Usually, the optically pumped carrier density at the saturable absorbing layer is about $2\text{-}4\times10^{18}cm^{-3}$. For lower doping concentrations, we could not obtain a solution for self-sustained pulsation. It becomes obvious that the high doping at saturable absorbing layer is indispensable for pulsation.

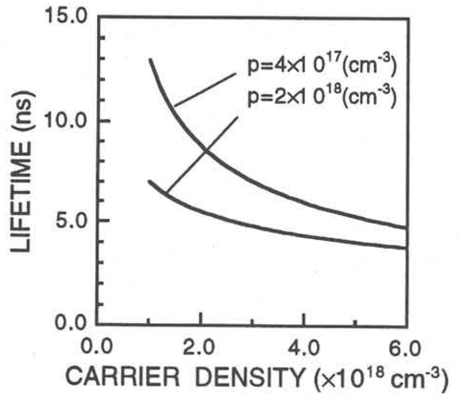

Fig. 1. Relationship between carrier lifetime and optically pumped carrier density in the saturable absorbing layer.

3. FABRICATION

Schematic cross section of transverse-mode stabilized laser diode with a ridge stripe structure is shown in Fig. 2. The epitaxial growth of the laser structure was carried out on 10° off (100) n-GaAs substrate (n=2×10^{18}cm^{-3}) by low pressure MOVPE. A double heterostructure consists of the following layers: an n-GaAs buffer layer (0.3μm, n=1×10^{18}cm^{-3}), an n-$(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ cladding layer (1.1μm, n=5× 10^{17}cm^{-3}), an undoped multiple quantum well (MQW) active layer, a saturable absorbing layer structure, a first p-$(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ cladding

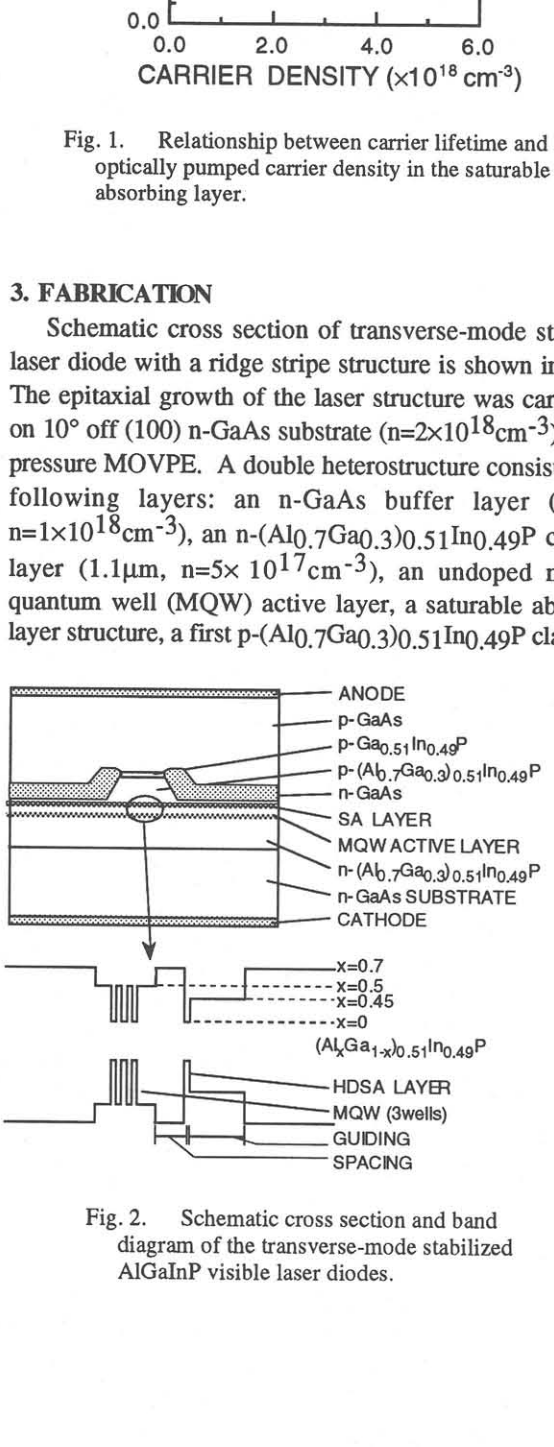

Fig. 2. Schematic cross section and band diagram of the transverse-mode stabilized AlGaInP visible laser diodes.

layer (p=4×10^{17}cm^{-3}), a p-$Ga_{0.51}In_{0.49}P$ etch stop layer, a second p-$(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ cladding layer (0.9μm, p=5×10^{17}cm^{-3}), a p-$Ga_{0.51}In_{0.49}P$ layer (p=1×10^{18}cm^{-3}), and a p-GaAs capping layer (p=5×10^{18}cm^{-3}). The band diagram of the MQW active layer and the saturable absorbing layer structure is also shown in Fig. 2. Al composition is denoted by x. The MQW active layer consists of three $Ga_{0.51}In_{0.49}P$ wells separated by $(Al_{0.5}Ga_{0.5})_{0.51}In_{0.49}P$ barriers. The saturable absorbing layer structure consists of a p-$(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ spacing layer, a p-$Ga_{0.51}In_{0.49}P$ saturable absorbing layer (p=2×10^{18}cm^{-3}), a p-$(Al_{0.45}Ga_{0.55})_{0.51}In_{0.49}P$ optical guiding layer (p=4×10^{17}cm^{-3}). The thickness of first p-cladding layer, which is the distance between the MQW active layer and the etch stop layer, is defined to be 0.2μm. The current spreading effect outside the ridge stripe can be neglected due to the thin first p-cladding layer. A mesa of the ridge stripe was selectively buried by an n-GaAs current blocking layer (n=3×10^{18}cm^{-3}). Finally, a p-GaAs contact layer (p=5×10^{18}cm^{-3}) was overgrown. The refractive index step difference between the inside of the ridge stripe and outside was controlled by the thickness of the first p-cladding layer. In this structure, the refractive index step difference was designed to be 2.22×10^{-2}. The index step is enough large so that the optical mode spreading is negligible outside the ridge stripe. The width of the ridge stripe was 4.8μm at the bottom. We fabricated the 500-μm-long devices.

4. CHARACTERISTICS

The typical threshold current of this device was 65mA at room temperature. The lasing wavelength was 656nm. Beam divergence angles parallel and perpendicular to the junction plane were 10.1° and 28.1°, respectively, resulting in a small aspect ratio of 2.78. The astigmatism was 3μm, which is very small compared to that of the conventional devices, which is as large as 10μm. These good characteristics for optical disk systems can be obtained by adopting the saturable absorbing layer.

Time dependence of the output power at the average output power of 5mW is shown in Fig. 3. The self-sustained oscillation with a frequency of 0.82GHz was observed. The self-sustained pulsation was confirmed to be maintained up to the output power of 10mW. The temperature dependence of RIN was measured. At the frequency of 2.0MHz with a resolution band width of 30KHz (Δf) and at the optical feedback of 1.0%, RIN was below -138 dB/Hz in the temperature ranging from 20 to 50°C as shown in Fig. 4. Since the low noise characteristics is attained also at high temperature, this laser is a promising candidate for practical application to optical disk systems.

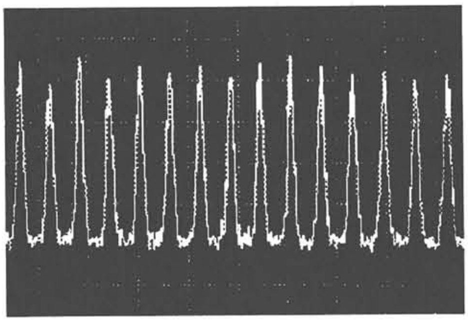

Fig. 3 . Time dependence of the output powe1 measured by using an optical oscilloscope at an average power of 5 mW. The continued oscillation with a frequency of 0.82GHz was confirmed. (Horizontal: 2ns/div.)

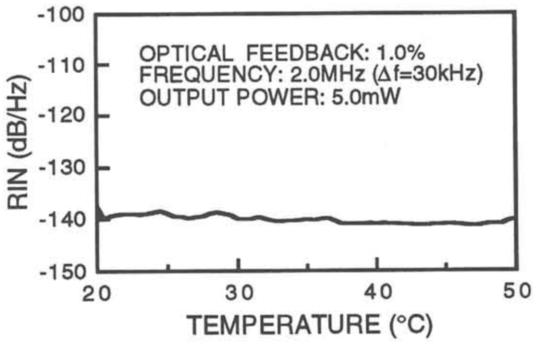

Fig. 4. Temperature dependence of the relative intensity noise (RIN) at the output power of 5.0 mW. Low noise characteristics was realized in the high temperature range as well as low range.

5. CONCLUSIONS

650nm-band AlGaInP visible laser diodes having very low intensity noise characteristics with self-sustained pulsation was successfully demonstrated by adopting highly doped saturable absorbing layer. 500-μm-long devices were fabricated, resulting in the typical threshold current of 65mA at room temperature. The lasing wavelength was 656nm. The RIN was below -138 dB/Hz in the temperature ranging from 20 to 50°C at the output power of 5mW. The self-sustained pulsation maintained up to the output power of 10mW. These lasers are promising candidates as optical sources for optical disk systems.

Acknowledgment

The authors wish to thank T. Fukuhisa, A. Ishibashi for their considerable support. We also thank M. Mannoh, A. Takamori for their useful discussions, and K. Ohnaka, T. Onuma for their instructive suggestions and encouragement.

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