論 文

AlGaAs /GaAs 레이저 다이오우드의 열처리에 의한 개선에 관한 연구

正會員 程 炫 必* 謝可舟** 魏楸良** 正會員 李 潤 鉉***

Improvement of AlGaAs /GaAs Quantum Well Laser Diodes by Thermal Annealing

Hyon Pil Jung,* Kezhou Xie,** Chu Ryang Wie,** Yun Hyun Lee*** *Regular Members*

ABSTRACT

In order to investigate the improvements of relatively poor characteristics of short wavelength AlGaAs /GaAs laser diodes which are useful as a light source for short distance communication systems, the low temperature (<680℃) grown AlGaAs /GaAs GRINSCH-QW laser diodes by molecular beam epitaxy have been studied by photoluminescence as a function of rapid thermal annealing(RTA) temperature. It is shown that guantum well photoluminescence intensity increased substantially by a factor of 10 after RAT at 950℃ for 10 sec. This is related to the reduction of non-radiative recombination in the guantum well region. The threshold current of annealed laser diode is reduced by a factor of 4, confirming the improvement of laser diode quality by rapid thermal annealing.

要 約

단거리 통신 시스팀의 광원으로 유용한 단파장 AlGaAs /GaAs레이저 다이오우드의 열악한 특성을 개선하기 위하여 MBE에 의해 낮은 온도에서 성장한 AlGaAs /GaAs GRINSCH-QW 레이저 다이오우드를 RTA온도의 변화에 좌우되는 포토루미네센스에 의하여 연구하였다. 950℃에서 10초동안 RTA처리를 한후 양자우물 포토루미네센스의 세기는 대체로 10배정도 증가하는것을 보여주었다. 이것은 양자우물 영역에서 발광되지 않는 재결합이 감소된것과 관련된다. 열처리된 레이저 다이오우드의 임계전류는 4배로 감소되었으며 RTA에 의하여 레이저 다이오우드의 질이 개선되었음이 확인되었다.

I. Introduction

The optical fiber communication system has

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*朝鮮大學校 併設工業專門大學
**SUNY-Buffalo Dept. of ECE
***韓國航空大學校 航空通信情報工學科
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many advantages over the conventional metal-wire communication system[1]. They are the smaller size, lighter weight, wider bandwidth with lower propagation loss, longer distance between repeaters, higher transmission capacity in system, lower system cost per channel, electrical isolation of output from input in data paths, immunity to electromagnetic interference, and freedom from signal leakage and cross talk[2]. Based on the distance of coverage area, telecommunication systems can be categorized as a subscriber loop, an intra-city network, an inter-city network, and an international network. The information density is relatively low in a subscriber loop. However, intra-city and inter-city networks require relatively high bit rates and long distance transmission spans. Optical fiber communication systems with the semiconductor lasers as the light source are being actively developed and actually deployed. The optical fiber communication has practical advantages over the conventional communication technology in terms of economy and maintenance also.

Typical silica fibers show low propagation loss in a wide wavelength ranges from 0.8 to 1.6μm. The propagation loss decreases with the increase of wavelength in this wavelength range[3,4,5]. The lowest propagation loss is obtained at wavelengths around 1.55μm[3]. The specific feature of no material dispersion appears at 1.3μm, which means no difference in propagation speed for light with different wavelengths[6]. The wavelength ranges of semiconductor light emitters and detectors are limited by the bandgap of the semiconductor materials[7]. For light emitters, AlGaAs lasers and light emitting diodes(LEDs) emit the light in the wavelength range from 0.7μm to 0.9μm by controlling x of the Al composition in the $Al_xGa_{1-x}As$ active layer.

InGaAsP lasers and LEDs emit light in the wavelength range from 1.1 to 1.65μm by controlling x of the Ga composition and y of the As composition in the $In_{1-x}Ga_xAs_yP_{1-y}$ active layer. The former wavelength range is called the "short wavelength" range and the latter wavelength range is called "long wavelength" range. They are applied to shorter (<10km) and longer (>10km) distance communication system respectively.

A system with an AlGaAs laser for the 0.8μm wavelength range and graded index multimode fiber is applied to intra-city networks with bit rates 32-140Mb/s and transmission span shorter than 10km. When more telecommunication channels are required in a metropolis, the optical fiber communication system is effective because a large number of optical fiber can be installed by withdrawing an existing metal-wire cable from city duct.

The objective of this paper is to explore the ways to improve the AlGaAs laser diode used as light source in shorter distance communication systems. The AlGaAs/GaAs laser diode is also a very important element in the high speed optical-electronic integrated-circuit(OEIC), computer communication, optical data storage and laser printer, etc[8]. In all its applications, the threshold current is a critical parameter. In order to obtain a low threshold current, the laser diode structure has to be grown at a high substrate temperature, typically above 680℃[9]. However, as reported by several researchers, there are a number of problems associate with high temperature growth. These are the high Ga desorption rate, high As flux requirement, dopant diffusion and growth non-uniformity[10,11]. Thus a lower growth temperature is desired. But some means must be developed to reduce the high threshold current associated with a lower temperature growth. Rapid thermal annealing(RTA) has been shown to increase the AlGaAs material quality. The RTA was applied to a series of AlGaAs/GaAs graded-index separate-confinement heterostructure(GRIN-SCH) single quantum well laser diode structures grown at low substrate temperatures (<680℃) by molecular beam epitaxy(MBE). Photoluminescence spectroscopy was used to study the effect of RTA on the laser diode samples. We showed that the quality of laser diode is improved substantially by RTA.

Ⅱ. Laser Diode Structure and Fabrication Process

The laser diode structure used in this study is shown in Fig.1. When a bias is applied to the diode, the holes are injected into the active quantum well through the p-type-doped top cladding layer, and the electrons are injected from the n-type-doped lower cladding layer. The electrons and holes are confined to its central GaAs quantum well, which is surrounded by graded $Al_xGa_{1-x}As$ layers having a higher bandgap(x varies between 0.25 to 0.55). Initially at low current, there is a spontaneous emission in all directions. As the current is increased, stimulated emission occurs and a monochromatic and coherent light is produced. When a threshold current is reached at which the optical gain equals the total optical loss in the cavity, a steady-state condition is reached and laser light is emitted from the quantum well region. All laser diodes are operated in this steady-state condition. The photon energy is determined by the energy difference between electron energy level and hole energy level in the quantum well. The optical mode is guided within the graded region because it has a higher index of refraction than the cladding layers(x = 0.55).

The laser structures were grown by MBE on a 2-inch-diameter n^+-doped GaAs substrates A silicon-doped buffer layer(0.5㎛ GaAs, $n = 1\times10^{18} cm^{-3}$) is grown on the substrate, which is followed by the lower cladding layer(1.5㎛ $Al_{0.55}Ga_{0.45}As$, $n = 1\times10^{18}cm^{-3}$). The core of laser consists of a parabolically graded region(0.175㎛ $Al_xGa_{1-x}As$, $n = 1\times10^{17}cm^{-3}$), an undoped 80A GaAs quantum well, and a parabolically graded region(0.175㎛ $Al_xGa_{1-x}As$, $p = 1\times10^{17}cm^{-3}$). The top cladding layer(1.5㎛ $Al_{0.55}Ga_{0.45}As$, $p = 1\times10^{18}cm^{-3}$) is followed by a 0.1㎛ heavily p-doped GaAs contact layer. The growth temperature of quantum well was varied from 620℃ to 725℃. In all cases, the growth temperature for the rest of the structure was 15℃ higher. In the following discussion, the growth temperature is referred to the quantum well growth temperature. All other growth conditions were kept constant. The laser diodes for testing threshold current was fabricated by first mesa etching 60㎛ strips on the samples and then cleaving samples into 500㎛ width bars. The Ohmic contacts are formed by evaporating Au to P^+ cap layer and AuGe /Ni to n^+ substrate. For the annealing study, the samples were annealed using an A.G. Associate HeatPulse 210T RTA system in N_2 atmosphere with proximity capping. The annealing temperatures and durations were 850℃ 15s, 900℃ 15s and 950℃ 10s. The photoluminescence was measured on the as-grown and annealed sample at 21K using a 0.25m monochromator with a 6mW HeNe laser as the light excitation source.

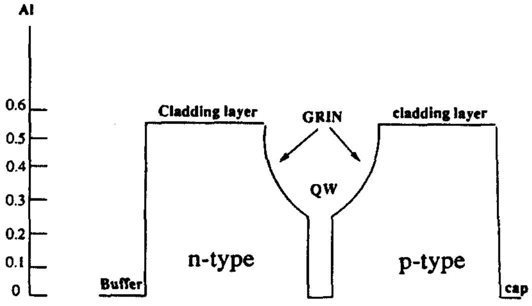

Fig.1. The diagram of GRINSCH-QW laser diode structure.

Ⅲ. Photoluminescence and laser threshold current

The as-grown samples were first characterized by photoluminescence and threshold current. As shown in Table Ⅰ, the threshold current increased with decreasing growth temperature. It is noticed that the threshold current is low if the growth temperature is higher than 680℃. The ratio of the highest threshold current to the lowest threshold current is about 10. Fig.2 shows

Table Ⅰ. The threshold current densities of the laser diodes as a function of post-growth annealing temperature.

Sample#	466	469	470	471	467	468	478	483
T_{QW}(℃)	620	635	650	665	680	695	710	725
J_{th}(A/cm^2) as-grown	>6333	4625	2102	1044	437	423	451	336
850℃ RTA	>6333	1927	1106	652	-	-	-	-
900℃ RTA	>6333	1553	920	590	-	-	-	-
950℃ RTA	>6333	1423	730	573	-	-	-	-

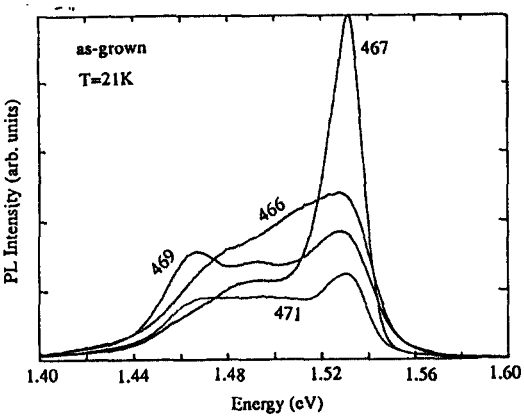

Fig.2. Photoluminescence spectra of as-grown samples. The quantum well growth temperature varied from 620℃ to 680℃.

photoluminescence of the samples grown at 620℃ ~680℃. For the sample grown at 680℃ which has the lowest threshold current, there is a distinct quantum well photoluminescence peak at 1.532 eV. The other broad peak at lower energy is from GaAs cap layer and substrate. However, the spectra show a broader and much weaker quantum well photoluminescence peak for the sample grown below 680℃, indicating a much reduced quantum efficiency. This is consistent with high threshold current of these samples. Both the photoluminescence intensity and the laser threshold current depend critically on the quantum well quality. It has been shown that the non-radiative recombination at the quantum well interface region is responsible for the high threshold current[9].

Thus the samples grown at <680℃ were annealed by RTA. Photoluminescence was used to probe the quality of the annealed samples. The photoluminescence spectra of four annealed samples are shown in Figures 3-6 as a function of annealing temperature. The photoluminescence spectrum of the as-grown samples were included as a reference. It is cleary shown that after annealing, quantum well photoluminescence be-

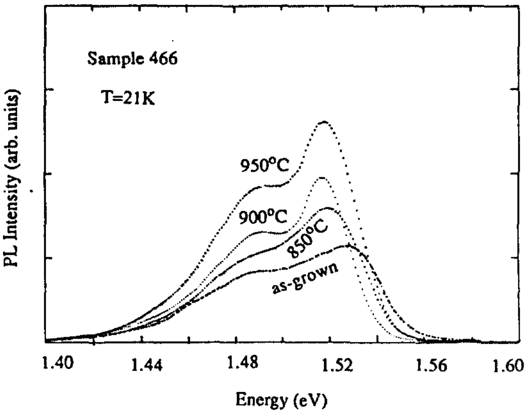

Fig.3. Photoluminescence of sample 466 grown at 620℃ as a function of post-growth annealing temperature.

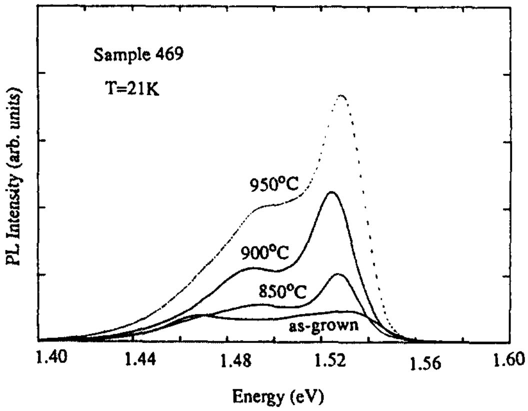

Fig.4. Photoluminescence of sample 469 grown at 635℃ as a function of post-growth annealing temperature.

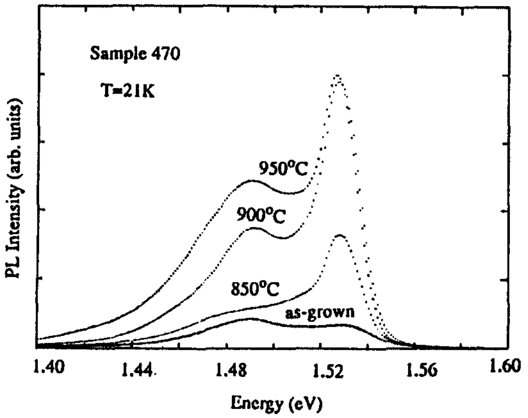

Fig.5. Photoluminescence of sample 470 grown at 650℃ as a function of post-growth annealing temperature.

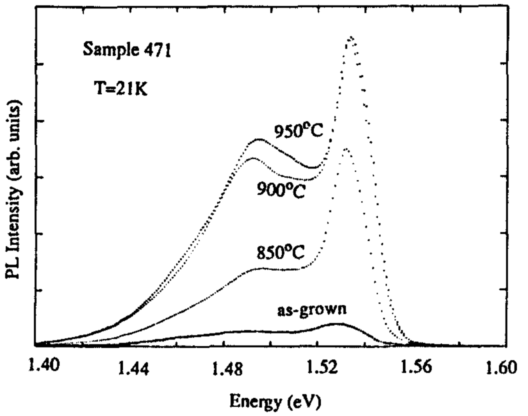

Fig.6. Photoluminescence of sample 471 grown at 665℃ as a function of post-growth annealing temperature.

came a dominant peak and increased with increasing annealing temperature. The increase of luminescence quantum efficiency in the quantum well can only be due to the decrease of the non-radiative recombination rate, since due to its intrinsic nature, the radiative rate is not expected to change by annealing[12]. This is supported by the fact that there is no shifting in the quantum well photoluminescence peak position, indicating that there is no interdiffusion at quantum well interfaces during the rapid thermal anneaing. It is noticed that quantum well photoluminescence intensity after 950℃ annealing decreased with decreasing the growth temperature. This indicates that there is still a higher non-radiative recombination rate in the lower temperature grown samples. Laser diodes were fabricated and tested for each annealed sample. There is a considerable reduction in the threshold currents for annealed diodes as shown in Table Ⅰ. Some threshold currents are close to the value of originally good diodes. The ratio of threshold current of the low-temperature-grown sample to that of the high temperature grown sample is reduced from about 10 in as-grown case to about 3 after annealing at 950℃ as shown in Fig.7.

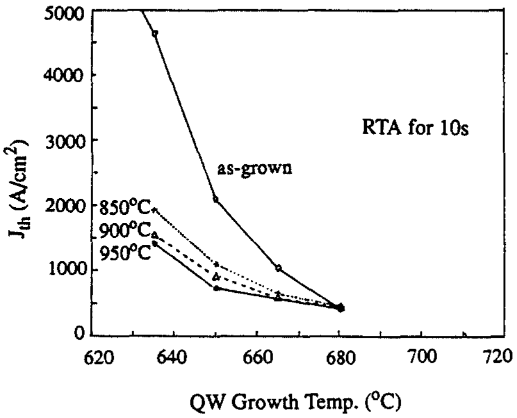

Fig.7. The laser threshold current densities as a function of post-growth annealing for samples 466, 469, 470, and 471.

Fig.8. shows the threshold current densities of the laser diodes as a function of the quantum well photoluminescence peak intensity. Straight lines through the data points are arbitrarily drawn lines to indicate a rough dependece of the change in threshold on the change in photoluminescence intensity. The different slopes of these straight lines indicate that the increased photoluminescence intensity in samples 469 and 470 is more strongly related with the reduced threshold current than in sample 471. Relation of the improved

threshold current with the variations in the interface state density and the I-V characteristics is decreased in our other paper [13].

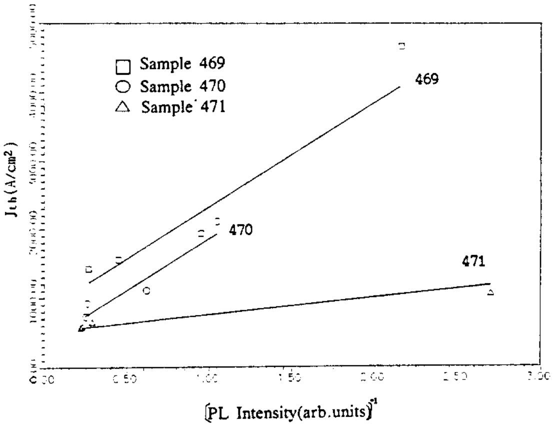

Fig. 8. The threshold current densities of the laser diodes as a function of the inverse of the photoluminescence intensity.

IV. Summary

There are a number of reports on the possible origin of the high threshold current in the laser diode grown at low substrate temperature [14]. The high impurity sticking coefficient and formation of intrinsic defect such as Ga vacancies are the two most often mentioned causes for the poor interface quality at GaAs/AlGaAs inverted interface. The secondary ion spectroscopy measurements showed accumulation of oxygen impurities at the inverted interface[11]. The annealing reduces the non-radiative recombination center density. We believe that accumulation of oxygen impurities at the inverted interface would play a more important role in determining the interface quality. The diffusion of these accumulated impurities away from the interface region may be responsible for the improvement of quantum well interface quality by the thermal annealing.

As this work demonstrates, the rapid thermal annealing is an effective way to improve the quality of laser diode. The photoluminescence spectroscopy is a very sensitive tool in probing the quality of laser diode structures. By using post-growth annealing, the laser structure can be grown at a lower substrate temperature but having a similarly good quality in the final device. The electrical measurement will be done on these diodes to further clarify the physical mechanism responsible for the improved laser diode quality.

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程 炫 必(Hyon Pil Jung) **正會員**
1948년 8월 15일생
1971년 2월 : 한국항공대학 항공통신공학과 졸업
1983년 8월 : 조선대학교 대학원(공학석사)
1992년 2월 : 한국항공대학 항공전자공학과 박사과정 수료
1977년 3월 ~ 현재 : 조선대학교 병설공업전문대학 전자통신과 부교수

謝 可 舟(Kezhou Xie) **正會員**

魏 楸 良(Chu Ryang Wie) **正會員**
State University of New York at Buffalo Dept. of ECE

李 潤 鉉(Yun Hyun Lee) **正會員**
1941년 8월 24일생
1965년 2월 : 한국항공대학 전자공학과 졸업
1979년 2월 : 단국대학교 대학원(공학석사)
1985년 2월 : 경희대학교 대학원(공학박사)
1975년 : 기술사 취득
1976년 ~ 현재 : 한국항공대학 항공통신정보공학과 교수
※주관심분야 : 마이크로파 및 광통신공학