Structural and Compositional Control of the Output Wavelength of Very High Power 0.98 μm GaInAs Lasers for Pumping Fiber Amplifiers

T. R. Chen, Y. H. Zhuang, W. K. Marshall, Y. J. Xu, and A. Yariv

Abstract—**The procedure for design and fabrication of high-power InGaAs strained-layer single-quantum-well lasers emitting at 0.98 μm is described. An output power of 265 mW at 0.98 μm has been demonstrated.**

ONE of the key components for erbium-doped fiber amplifiers (EDFA) is the pump source. The commonly used pumps for EDFA are InGaAsP lasers at 1.48 μm and strained layer InGaAs lasers at 0.98 μm. The InGaAs laser is advantageous in terms of high pumping efficiency and optimal amplifier noise performance.

There exists extensive literature on various aspects of the performance of EDFA's. Little has been reported, however, on the preparation of pump sources. The basic requirements for the 0.98 μm InGaAs pump lasers are the following: the lasing wavelength should be in a certain range around 0.98 μm. Although there are no reports on the exact restriction of the wavelength coverage, it is believed that the peak wavelength $\lambda_p = 0.980 \pm 0.002$ μm [1], [2] is the proper value to be considered in terms of maintaining high pumping efficiency. Secondly, the output power of the pump laser at 0.98 μm should be high enough to generate the desired amplified power. This is due to the fact that in the saturated regime where such amplifiers are traditionally operated, the amplified output power is proportional to the pumping power [3], so that higher pumping power leads to higher output power. Thirdly, for efficient coupling into the fiber, the pump laser should operate in a single lateral mode with a narrow beam-divergence angle. An index-guided laser structure is thus desirable. Fourthly, a single-frequency output from the pump source is desirable but it is not a necessary condition. It has been shown that a multilongitudinal-mode InGaAs laser with a spectral width of ~4 nm can serve as a good pump source [2].

In this letter, we report on the design, fabrication and characterization of a high-power strained-layer (SL) InGaAs single-quantum-well (SQW) laser. The lasers emit at 0.980 ± 0.002 μm. They deliver over 100 mW CW optical power at room temperature in a stable single lateral mode with a beam divergence of 15 ~ 20°. The maximum CW output power measured is 265 mW. The lasers have been successfully used as pump sources for an EDFA. High gain and high output power were obtained [2].

A hybrid technique of molecular beam epitaxy (MBE) plus liquid phase epitaxy (LPE) was used for the fabrication of our InGaAs pump source. The GRINSCH-SQW-SL InGaAs/AlGaAs material was prepared by MBE technique [4]. The width of the SQW was 50 Å. To obtain effective two-dimensional optical and carrier confinement, a buried heterostructure (BH) laser was made by an LPE regrowth technique. The width of the active layer was 2.5 ~ 3 μm. (Fig. 1) To achieve high output power, the internal optical loss (α_i) must be low and the internal quantum efficiency (η_i) should be high, which characterized our high-quality MBE material and high-quality LPE regrowth. The measured α_i is in the range of 3 ~ 10 cm^{-1} while the η_i is typically 0.80 [5].

To obtain high output power from the front facet of a laser, the general approach is the use of a long cavity length (typically 0.7 ~ 1 mm) incorporating a combination of a high reflectivity (HR) coating on the rear facet and a low reflectivity (LR) coating on the front facet [6], [7]. The optimum reflectivity depends on the internal loss α_i and cavity length. A typical near-optimum combination of an HR of > 0.9 and an LR of 0.02–0.08 was used [8]. The minimization of the leakage current in the laser is also very critical [7].

It is known that the wavelength of the strained-layer InGaAs laser depends mainly on the In concentration and to a lesser degree on the width of the quantum well. However, we have found that the wavelength is also rather sensitive to the laser cavity length [9] and facet reflectivity [5]. Furthermore, the wavelength increases with increasing driving current. Therefore, tuning of an InGaAs laser to 0.98 μm is a nontrivial task involving every step in the fabrication process. The major steps of our process are: first, control the In composition and quantum-well width in the MBE growth process to ensure that the peak fluorescence wavelength of the InGaAs active layer will be in the vicinity of 0.98 μm. Secondly, choose the proper laser cavity length (0.7–1.2

Manuscript received April 22, 1991. This work was supported by Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR).

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IEEE Log Number 9102057.

1041-1135/91/0800-0694$01.00

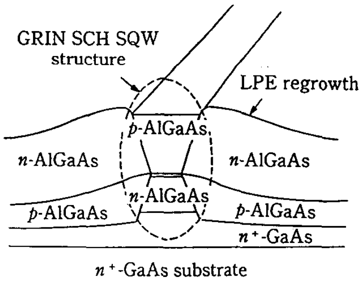

Fig. 1. Schematic structure of a BH-SL-SQW InGaAs/AlGaAs laser.

TABLE 1

Code of Laser	L (μm)	R_f, R_r	Ith (mA)	η_D (mW/mA)	λ_p (μm)	P_{max} (mW)
		0.3, 0.3	6.7	0.42	0.9857	
A_1	1325	0.3, 0.92	5	0.51	0.9904	
		0.07, 0.92	8.7	0.79	0.9797	265
		0.3, 0.3	13	0.34	0.9895	
A_3	1325	0.3, 0.9	9	0.44	0.9938	
		0.05, 0.9	16.5	0.6	0.9820	> 200
		0.3, 0.3	10	0.34	0.9854	
A_5	1325	0.3, 0.9	8.5	0.41	0.9890	
		0.08, 0.9	10.5	0.51	0.9814	> 180
		0.3, 0.3	12.5	0.35	0.9828	
		0.3, 0.9	8	0.51	0.9875	
B_4	970	0.1, 0.9	12.8	0.76	0.9785	
		0.18, 0.9	10.0	0.68	0.9809	> 160
		0.3, 0.3	13	0.33	0.9960	
B_3	1715	0.3, 0.05	17.5	0.5	0.9870	> 230
		0.9, 0.05	16	0.58	0.9912	
		0.3, 0.3	5.2	0.44	0.9527	> 140
F_4	440	0.3, 0.9	4	0.59	0.9617	

mm) to ensure that the peak lasing wavelength under the designed operating current (e.g., 200 mA) will be slightly to the red of 0.98 μm. In our case, 0.985–1.000 μm was a good starting range. Thirdly, tune the mirror reflectivities to ensure that the peak lasing wavelength under the operating current falls into the designed range, 0.980 $\pm$ 0.002 μm. We usually employed a high-reflectivity coating with $R \geq 0.9$ on the rear facet and then adjusted the reflectivity on the front facet until the right wavelength was obtained. This may require several iterations of the coating process and may even necessitate a compromise between maximum output power and the lasing wavelength since the two may be reached at different mirror reflectivities. In principle, a proper choice of cavity length makes it possible to optimize the power and the wavelength simultaneously. Also, fine tuning of the wavelength using temperature is always available, especially when the wavelength is a little on the long side. However, if an exact wavelength source is required, special measures have to be taken (e.g., DFB).

Using this procedure, we have successfully fabricated high-power GRINSCH-SQW-SL InGaAs/AlGaAs lasers and used them for EDFA experiments. The maximum CW output power at room temperature is in the range of 100–200 mW

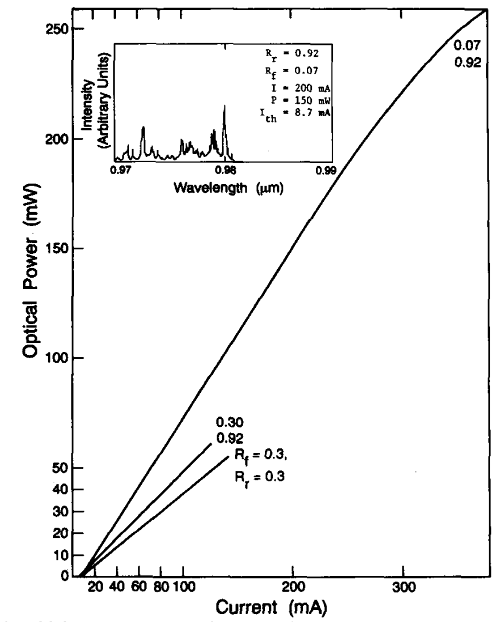

Fig. 2. Light-versus-current characteristics of a high power BH-SL-SQW InGaAs laser with different mirror reflectivities.

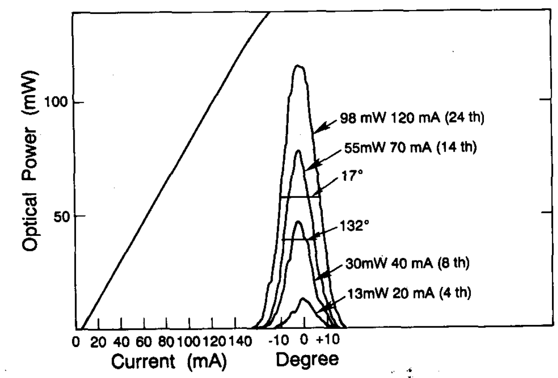

Fig. 3. Far field patterns of a high-power BH-SL-SQW InGaAs laser at different power levels.

with the highest power measured being 265 mW. The peak wavelengths of the lasers are in the range of 0.980 $\pm$ 0.002 μm. The external quantum efficiency for the front facet alone ranges 0.5–0.8 mW/mA. With an active-layer lateral width of 2.5–3 μm, most of the lasers operate in a single lateral mode with a beam divergence of 15–20°. In our EDFA experiments with these pump lasers, 30–35% power coupling efficiency was obtained for a 4 μm core diameter erbium-doped fiber.

Table I lists some of our representative lasers. It shows how the important parameters, such as threshold current Ith, external quantum efficiency η_D, peak wavelength λ_p, and maximum output power p_{max} change with mirror reflectivity. For lasers A_1, A_3, A_5, B_4, the powers and wavelengths are in the desired ranges. Laser B_3 represents a device with too long a cavity length and thus too long a lasing wavelength while laser F_4 is the opposite.

Typical L–I curves, far-field patterns and the evolution of

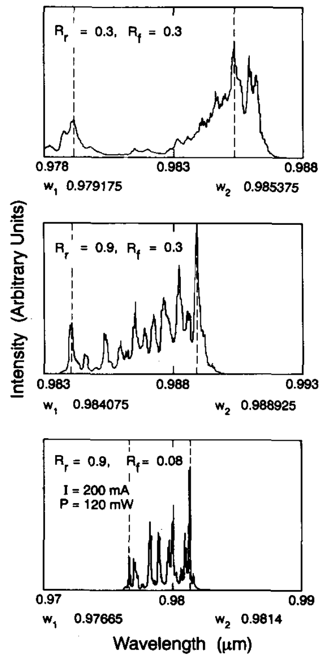

Fig. 4. Spectra of a high power BH-SL-SQW InGaAs laser with different mirror reflectivities.

lasing spectra with mirror coatings are presented in Figs. 2–4, respectively.

In conclusion, a procedure for design and fabrication of 0.98 μm InGaAs pump sources for EDFA's was discussed, and high power and high efficiency were demonstrated.

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