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Frequency doubling of an InGaAs multiple quantum wells semiconductor disk laser

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We demonstrate a good beam quality 483 nm blue coherent radiation from a frequency doubled InGaAs multiple quantum wells semiconductor disk laser. The gain chip is consisted of 6 repeats of strain uncompensated InGaAs/GaAs quantum wells and 25 pairs of GaAs/AlAs distributed Bragg reflector. A 4 × 4 × 7 mm^3 type I phase-matched BBO nonlinear crystal is used in a V-shaped laser cavity for the second harmonic generation, and 210 mW blue output power is obtained when the absorbed pump power is 3.5 W. The M^2 factors of the laser beam in x and y directions are about 1.04 and 1.01, respectively. The output power of the blue laser is limited by the relatively small number of the multiple quantum wells, and higher power can be expected by increasing the number of the multiple quantum wells and improving the heat management of the laser.

1. Introduction

Practical and cost-effective blue coherent radiations are of highly interest in many important applications such as laser display, high density optical storage, underwater communication system, and so on. Compare with others display methods, the advantages of laser display are its large color gamut, high brightness, long lifetime and low power dissipation. As one of the three primary colors which cannot be absent, blue laser plays a key role in the development of laser display [1]. For high density optical storage, the current blue-ray disc can achieve 22 GB storage capacity on a 12 cm disc, six times than that of the existing technology. As the third generation storage technology, blue-ray storage will become the major technology of the forthcoming digital video communications [2]. In underwater communication system, the blue laser communication is the way having the least attenuation and the fastest bit rate [3].

Blue laser diodes are commercially available now, however, the epitaxial growth of the gain wafer is sophisticated and its distortional light beam cannot be used directly for many applications [4]. The dependences of high-volt electrical power of the technological maturity argon ion blue lasers make it inconvenient in some applications, and the gas-state gain medium of the laser limits its output energy density [5]. Another kind of widely used blue laser, solid-state blue laser, has complicated cavity structure with very limited emitting wavelength [6].

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A new type of semiconductor lasers, optically pumped semiconductor disk laser (OP-SDL), has straightforward and simple cavity and can produce multi-watts output power. Compared with the solid-state laser and the traditional semiconductor laser, the unique feature of a SDL is its successful combination of the excellent beam quality, power scalability and the emitting wavelength adjustability [7–9]. By intra-cavity frequency doubling, the laser wavelength of a SDL can be extended to the visible and ultraviolet waveband [10].

The earliest blue SDL was reported by Raymond et al., in 1999. The laser cavity was composed of two reflective mirrors, a $KNbO_3$ nonlinear crystal was inserted for frequency doubling, and 490 nm blue light of 5 mW output power was produced [11]. By optimizing the number of multiple quantum wells and employing carrier blocking layers, J.Y. Kim et al. demonstrated 1.9 W continuous-wave output power at 460 nm blue wavelength in 2007, the power conversion efficiencies (output power/input power) of 22.5% and 9.5% were realized for 920 nm and 460 nm, respectively [12]. In 2011, A. Hein et al. presented 460 nm blue output powers between 1.35 W and 1.61 W by the use of a BiBO as the nonlinear crystal, and the optical-to-optical conversion efficiency was 41.5% [13]. So far, frequency doubled SDLs have already been extensively reported in the green and yellow-orange spectral range [14–16], however, there are few reports on the blue spectral range of 460–490 nm.

In this paper, InGaAs/GaAs multiple quantum wells (MQWs) are grown in the semiconductor gain wafer to obtain fundamental emission at 966 nm, and GaAs/AlAs distributed Bragg reflector (DBR) is employed to produce about 100 nm bandwidth high reflectivity centering at 966 nm. A type I phase-matched BBO nonlinear crystal is inserted, and a straight linear cavity and a V-shape folded cavity are used respectively for experimental comparison of the second harmonic generation. 210 mW output power 483 nm blue SDL is achieved when the absorbed pumping power reached 3.5 W. The M^2 factors of 1.04 and 1.01 for x and y directions show the good beam quality of the blue laser.

2. Experiment setup

The epitaxial structure of the gain chip is shown in Fig. 1(a), and the sequence of epitaxial growth is as following: 100 nm buffer layer on GaAs substrate is added to improve the quality of epitaxial growth firstly, then 200 nm $Al_{0.85}Ga_{0.15}As$ is grown as the etch stop layer, 20 nm GaAs cap layer is used to protect the wafer from oxidation when the etch stop layer is removed. Next, a 207 nm thick high band gap $Al_{0.6}Ga_{0.4}As$ window layer is introduced as the high barrier layer to prevent the photo-induced carriers from nonradiative recombination at surface of the wafer. The active region is consisted of 6 repeats strain uncompensated InGaAs/GaAs MQWs and 25 pairs GaAs/AlAs DBR. The every single QW includes 8 nm $In_{0.185}Ga_{0.815}As$ well

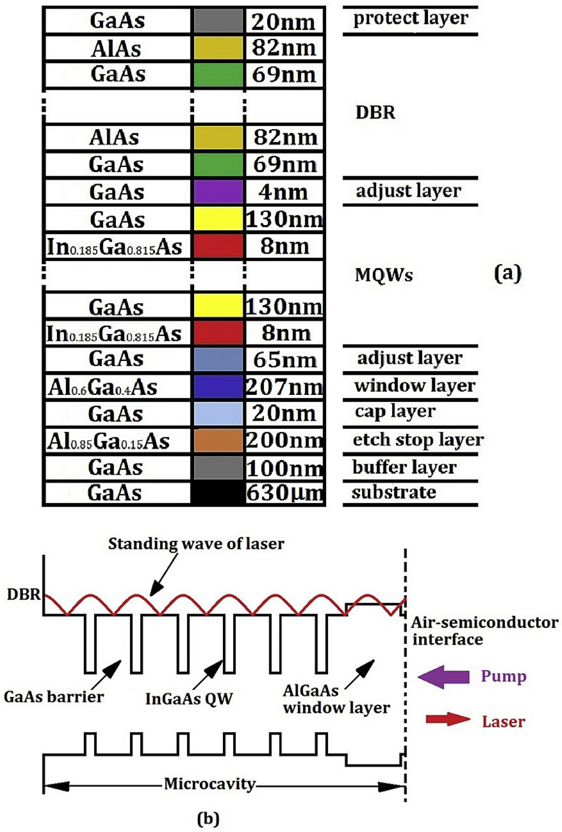

Fig. 1. Epitaxial structure of gain chip (a), and the schematics of active region (b).