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Passively Mode Locked Diode-End-Pumped Nd∶YAG Laser with $In_{0.25}Ga_{0.75}As$ as Output Coupler

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Abstract: A novel InGaAs(LT-$In_{0.25}Ga_{0.75}As$) absorber grown by metal organic chemical vapor deposition at low temperature is presented. Using it as well as an output coupler, passive mode locking, which produces pulses as short as several hundred picoseconds for diode-end-pumped Nd∶YAG laser at 1.06μm, is realized. The pulse frequency is 150MHz.

Key words: SESAM; $In_{0.25}Ga_{0.75}As$; output coupler; modelock
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1 Introduction

Since 1990s there has been increasing interest in the development of picosecond diode-pumped solid state lasers, which have numerous applications in medicine, material processing, free electron lasers, pulse laser for distance measurement, and so on. Passive mode-locking technique for cw solid-state lasers based on saturable absorbers especially semiconductor saturable absorber mirror (SESAM) seems to be favorable because of the typically shorter pulse durations and the simpler setup than those of actively mode-locked lasers. Such structures consist of multiple quantum wells grown by molecular beam epitaxy or metal organic chemical vapor deposition. Mode locking with such a device is performed by a nonlinear bleaching process of interband absorption. The absorbers can also be used to initiate Kerr-lens mode locking[1] and to stabilize the mode-locking operation. Mode locking with SESAMs[2~5] is based on a resonant saturation of interband absorption, and consequently the bandgap of the material has to be adjusted to the emission wavelength of the laser. This adjustment makes a highly sophisticated growth technique mandatory for producing multiple-quantum-well structures, requiring considerable effort in production and making SESAM structures quite expensive. Thus semiconductor elements with a simpler structure and a nonresonant nonlinearity for mode locking are interesting subjects of research. Leitner *et al.*[3] introduce a mode-locking device that is based on defocusing of the intracavity beam in a thin layer of low-temperature-grown GaAs(LT-GaAs). Carriers generated by non-resonant two photon absorption (TPA) in the semiconductor lead to a nonlinear change of refractive index, with a spatial profile determined by the laser beam. Defocusing by this index profile, which decays with a short carrier recombination time, results in fast loss modulation, allowing efficient self-starting mode locking of a diode-pumped Nd: glass fiber laser[3].

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2 Theory of LT-$In_{0.25}Ga_{0.75}As$ used for passively mode locked Nd∶YAG laser

In this paper we introduce a novel mode-locking device that is based on defocusing of the intracavity beam in a thin layer of low-temperature-grown $In_{0.25}Ga_{0.75}As$ (LT-$In_{0.25}Ga_{0.75}As$). LT-$In_{0.25}Ga_{0.75}As$ incorporates many As antisite (AsGa) defects that yield the saturable absorption. Recovery time can be controlled by the growth temperature and the modulation depth that depends on the thickness of the absorption layer.

The structure of LT-$In_{0.25}Ga_{0.75}As$ is as simple as that of LT-GaAs, and is easy to be grown. However, it does not work in the principle of TPA that leads to a nonlinear change of refractive index. The principle of LT-$In_{0.25}Ga_{0.75}As$ is as same as that of SESAMs. Mode locking with LT-$In_{0.25}Ga_{0.75}As$ is performed by a nonlinear bleaching process of interband absorption. When the ratio of In to Ga is changed, LT-$In_{0.25}Ga_{0.75}As$ can be used to mode lock for solid-state lasers at wavelength other than 1060nm as SESAMs do, while LT-GaAs is only for the wavelength near 1060nm. To make LT-$In_{0.25}Ga_{0.75}As$ work as SESAMs do, it should be coated with antireflection film and high reflection film, which is cheaper and more adjustable than SESAMs do. In conclusion, LT-$In_{0.25}Ga_{0.75}As$ represents the advantages of both SESAMs and LT-GaAs at the wavelength near 1060nm.

3 Manufacture of LT-$In_{0.25}Ga_{0.75}As$

The LT-$In_{0.25}Ga_{0.75}As$ layer was grown by metal organic chemical vapor epitaxy at a substrate temperature of 550℃. A 25nm thick GaAs barrier layer was grown at normal temperature (720℃) between the 10nm LT-$In_{0.25}Ga_{0.75}As$ and GaAs buffer layer which grown on the GaAs substrate in order to improve the quality of the surface of the GaAs substrate. There is another 25nm thick GaAs barrier layer on the top of the LT-$In_{0.25}Ga_{0.75}As$ layer, which acts as the protection layer from LT-$In_{0.25}Ga_{0.75}As$ layer to the air.

When the thickness of $In_{0.25}Ga_{0.75}As$ is above the critical thickness, the large lattice mismatch of $In_{0.25}Ga_{0.75}As$ on GaAs can cause degradations such as surface striations, which can lead to much nonsaturable loss. Therefore, we choose $In_{0.25}Ga_{0.75}As$/GaAs quantum well (QW) structure other than bulk $In_{0.25}Ga_{0.75}As$. The InGaAs/GaAs QW bandgap is not a very critical parameter, which is adjusted approximately to the lasing wavelength. Figure 1 shows the structure of growth recipe.

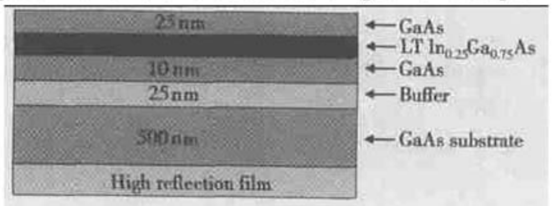

Fig. 1 $In_{0.25}Ga_{0.75}As$ absorber grown by MOCVD

In order to make the $In_{0.25}Ga_{0.75}As$ as an output coupler, one side of the absorber is coated with anti-reflection coating and the other side is deposited with high reflection coating. Anti-reflection film is a 1/4 wavelength thickness of the hybrid of ZrO_2 and Y_2O_3(4∶1). High reflection film is composed of $Al_2O_3/Si/SiO_2/Si$ multiple layers structure in order to obtain as high as 90% reflectivity. Absorber is 10nm thick $In_{0.25}Ga_{0.75}As$ grown at low temperature (550℃). Figure 2 shows the transmission spectrum of the saturable absorber. The reflectivity of the absorber at 1.06μm is 9%. We

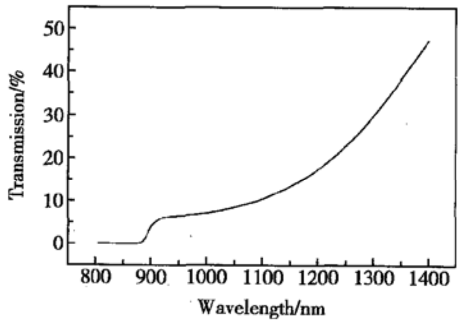

Fig. 2 Reflection spectrum of the output coupler type SESAM

make the transmission rate of the absorber near 10% in order to make it as an output coupler too. The anti-reflection coating is made in order to eliminate F-P effect, which will widen the duration of the pulse.

4 Passive mode locking of diode-end-pumped Nd : YAG laser with LT-$In_{0.25}Ga_{0.75}As$

Linear cavity structure is selected in passive mode-locked diode-end-pumped Nd : YAG laser because of its simplicity image disperse (as shown in Fig. 3). Pump source is 10W 808nm wavelength diode laser coupled by fiber of 400μm core diame-

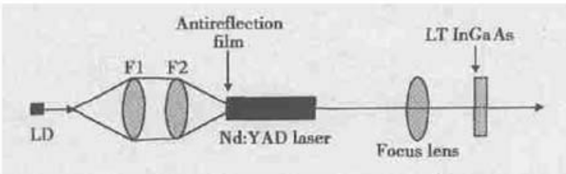

Fig. 3 Linear cavity of passive mode locking diode-end-pumped Nd : YAG laser with $In_{0.25}Ga_{0.75}As$

ter; F_1 and F_2 are two lens as collimating and focusing; the laser crystal is Nd : YAG with dimension of Φ3mm×5mm. Another focusing lens is inserted into the cavity to focus the beam on the absorber so that the optical intensity on the surface of absorber is large enough to make the absorber work in nonlinear region. The cavity length is about 100cm. The modelocking pulse output power is 1W. We obtained cw mode locking at the repetition rate of 150MHz (the interval of pulses is about 7ns, as shown in Fig. 4). The pulse duration is estimated to be several hundred picoseconds.

5 Conclusion

A novel LT-$In_{0.25}Ga_{0.75}As$ absorberas an

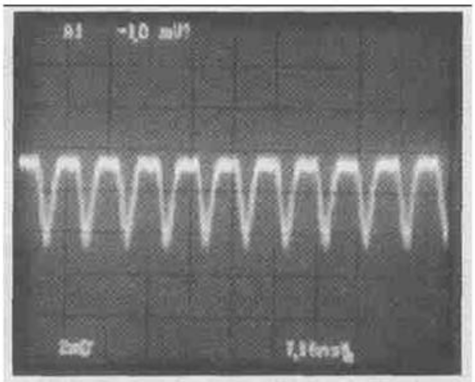

Fig. 4 CW passive mode locking trace The interval of pulses is about 7ns (accordingly, the repetition rate is 150MHz)

output coupler is reported, which is obtained cw mode locking in a diode-end-pumped Nd : YAG laser. The pulse width is about several hundred picoseconds. According to the transmission spectrum of the absorber, this device can be used to mode lock as short as 946nm wavelength in an Nd : YAG laser.

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半导体激光器端面泵浦 Nd∶YAG 激光器用 $In_{0.25}Ga_{0.75}As$ 吸收体被动锁模兼做输出镜

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摘要: 用金属有机气相淀积方法生长了一种新型的吸收体——低温 InGaAs (LT-$In_{0.25}Ga_{0.75}As$). 用这种吸收体兼做输出镜, 实现了 1.06μm 半导体端面泵浦 Nd∶YAG 激光器被动锁模, 脉冲宽度为皮秒量级, 重复率为 150MHz.

关键词: 半导体可饱和吸收镜; $In_{0.25}Ga_{0.75}As$; 输出镜; 锁模
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