第 25 卷第 10 期
2004 年 10 月

半 导 体 学 报
CHINESE JOURNAL OF SEMICONDUCTORS

Vol. 25, No. 10
Oct., 2004

800nm Semiconductor Absorber with Low Temperature Method and Surface State Method Combined Absorber for Kerr Lens Modelocking of Ti∶Al_2O_3 Laser

Wang Yonggang[1], Ma Xiaoyu[1], Cao Shiying[2] and Zhang Zhigang[2]

(1 *Institute of Semiconductors, The Chinese Academy of Sciences, Beijing* 100083, *China*)
(2 *Ultrafast Laser Laboratory, School of Precision Instrument and Optoelectronics Engineering, University of Tianjin, Tianjin* 300072, *China*)

Abstract: A novel 800nm Bragg mirror type of semiconductor saturable absorption mirror with low temperature method and surface state method combined absorber is presented. With which passive Kerr lens mode locking of Ti∶Al_2O_3 laser pumped by argon ion laser is realized, which produces pulses as short as 40fs. The spectrum bandwidth is 56nm, which means that it can support the modelocking of 20fs. The pulse frequency is 97.5MHz; average output power is 300mW at the pump power of 4.45W.

Key words: semiconductor saturable absorption mirror; surface states; low temperature; Bragg mirror
EEACC: 4330B
CLC number: TN389 **Document code**: A **Article ID**: 0253-4177(2004)10-1233-05

1 Introduction

The research of passive modelocking of ultrashort pulse lasers has grown into an active research area in recent years, which results in numerous record pulse durations and simpler, more compact laser designs. Sutter *et al.*[1] obtained pulses of sub-6-fs duration from a Kerr-lens mode-locked Ti∶Al_2O_3 laser at a repetition rate of 100MHz and an average power of 300mW. Ultrashort pulse technology has been applied to biomedical optics, high-speed communications, and the investigation of ultrafast nonlinear processes in semiconductor materials and devices. In order to be useful for widespread commercial applications, ultrashort pulse laser sources must be technologically simple, robust, and cost effective. Kerr-lens modelocking (KLM) of solid-state lasers has been the most successful approach for short pulse generation. KLM is a passive modelocking technique which utilizes the Kerr effect, or nonlinear index of refraction, to create an artificial fast saturable absorber. This technique is combined with intracavity dispersion management so that it can yield extremely short pulse durations. However, pure KLM is typically not self-starting and requires a critical cavity alignment. Keller *et al.* invented a broadband semiconductor saturable absorber mirror (SESAM) to start KLM and relax the critical cavity-alignment requirements. The pulse duration is limited by the remaining higher-order dispersion in the laser cavity, which is caused mainly by the prism pair. SESAM seems to be favorable because of the typically shorter pulse durations and the simpler setup than those of actively mode-locked lasers. Such structure consists of multiple quantum wells grown by molecular beam epitaxy or metal organic chemical vapor deposition. Modelocking in such a device is performed by a nonlinear bleaching process of in-

Received 5 January 2004, revised manuscript received 2 April 2004

terband absorption. Such absorbers can be used to initiate Kerr-lens mode locking and to stabilize the mode-locking operation. Mode locking with SESAMs[2~8] is based on a resonant saturation of interband absorption, and consequently the bandgap of the material has to be adjusted to or above the emission wavelength of the laser.

2 Manufacture of the SESAM

The SESAMs for Ti∶Al_2O_3 laser are divided into two kinds: broadband type and SBR(saturable bragg reflector) type[6]. The reflector of the broadband type of SESAM is often made from dielectric and gold (or silver), which requires technologies such as etching and coating so that much loss is led into the SESAM and the life of SESAM is shortened. At the same time, the complexity to make SESAMs increases greatly, which is disadvantageous to batch production. SBR type of SESAMs requires no etching procedures in their manufacture, which makes them the most promising method to realize products. SBR type of SESAMs have weak point in their narrow bandwidth, which limits their application in the field of modelocking with pulse duration less than 30fs. However, pulse with duraion of 30fs or longer is enough for the most of applications of ultrashort pulse lasers.

Figure 1 shows the structure of the SESAM. In this structure, DBR (distributed Bragg reflector) is composed of 25 pairs of $Al_{0.17}Ga_{0.83}As$/AlAs in order to obtain reflectivity as high as 98%. Absorber is GaAs/$Al_{0.17}Ga_{0.83}As$/GaAs sandwich structure. The absorption edge of GaAs quantum well is about 830nm. The bottom GaAs layer of the sandwich structure is grown at 550℃ (any other layers are grown at 720℃) by metal organic chemical vapor deposition (MOCVD), which is also the relaxation region for carriers generated by light. The recovery time of low temperature SESAM increases with the growing temperature of relaxation region. We choose 550℃ as higher growing temperature to decrease the nonsaturable loss, which is the main cause to damage or shorten the life of the device. To make the recovery time short enough, we adopt another relaxation mechanism: surface state at the same time. On the top of the sandwich structure, there is a thin region with high intensity of surface states at the interface of GaAs/air, which has the picosecond level relaxation time

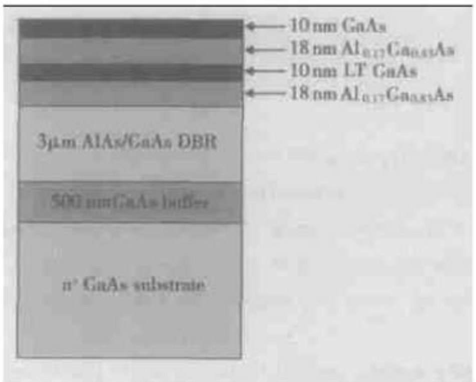

Fig. 1 Structure of the SESAM

or recovery time for carriers[9]. However, surface states are sensible to the condition of the interface of GaAs/air. When the SESAM exposes to air for a long time, its surface may be polluted by dust or something, which will change the recovery time greatly. Here we adopt sandwich structure with low temperature and surface states hybrid absorber, with which we realize low nonsaturable loss, high working stability, and long life. The bottom GaAs layer of sandwich structure is grown at 550℃ by MOCVD, which acts as an absorber that adsorbs special wavelength light and at the same time provides fast picosecond saturable absorption recovery time owing to the fast trapping of the electrons in the As_{Ga} and holes in the V_{Ga} generated from low temperature grown GaAs. The two mechanisms make SESAM a nonlinear absorber against the intensity of light so that it can refrains the side of a pulse and enhances the center of the pulse. At higher growth temperatures, large lattice mismatch between GaAs and adjacent material can cause surface striations to scatter the laser light. However, the mismatch of AlGaAs/GaAs is very little. The bandgap wavelength of GaAs is not a very critical parameter, which is adjusted approximately to or above the lasing wavelength. As antisites or Ga vacancy generate after the low temperature (LT) growth of GaAs by MBE or MOCVD when As fluence is excessively relative to Ga fluence. Figure 2 shows the reflection spectrum of the SESAM. The center wavelength is 817nm and the reflection bandwidth is about 30nm, which can support modelocking with pulse duration as short as 20fs.

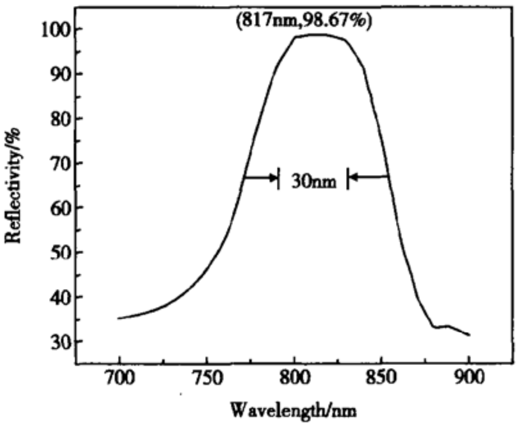

Fig. 2　Reflection spectrum of the SESAM

3　Experiment and results

In 1995, Brovelli[9] realized self-starting soliton modelocked Ti : Al_2O_3 laser using a thin semiconductor saturable absorber. Soliton modelocking is a modelocking mechanism in which the pulse is completely shaped by soliton formation, but stabilized by a slow saturable absorber. In soliton modelocking, self-phase modulation (SPM) and group dislay dispersion (GDD) are in balance for the formation and transmission of soliton. SPM and GDD are relatively independent, so we can modulate them separately, which reduces the difficulty of the adjustment of modelocking set-up. The pulse duration is about twentieth or thirtieth of the recovery time of SESAM. Generally, only by KLM modelocking we can obtain the shortest pulse duration. In 1996, Fluck *et al*.[10] demonstrate the fabrication of a broadband saturable absorber with a silver bottom mirror, with which they generate sub-10-fs pulses. Here, we adopt sandwich structure SESAM with two-layer of GaAs absorption layer, which is thick enough to obtain pulse short enough at the basis of 50nm bandwidth.

The set-up of experiment is shown in Fig. 3. We adopt a standard X type of fold cavity with a focusing concave mirror of 50mm radius of curvature to reduce the incident beam size upon the SESAM. A pair of prims at the end of long arm is

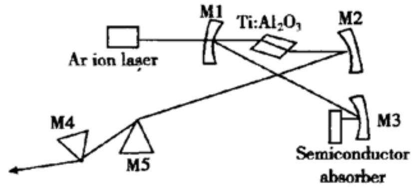

Fig. 3　Diode-pumped Ti : Al_2O_3 laser using an intracavity saturable Bragg reflectors with two-prism sequence for dispersion compensation

used to carry through dispersion compensation. The length of the crystal is 5mm. Pump source is 514nm argon ion laser. We obtain 300mW continuous modelocking output with 20% output coupler at the 4.45W pump power. Figure 4 shows the continuous wave modelocking diagram observed from oscillator. Figure 5 shows the autocorrelation trace of the resulting pulses. The relationship of the pulse repetition rate and the cavity

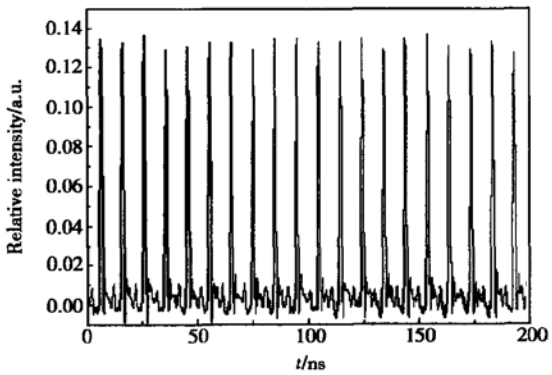

Fig. 4　Oscilloscope trace of continuous wave modelocking pulse train

length is: $F = c/2L$, where c represents the velocity of light, L the cavity length, and F the pulse repetition. In our experiment, the cavity length is about 150cm. The pulse repetition rate is 97.5MHz and

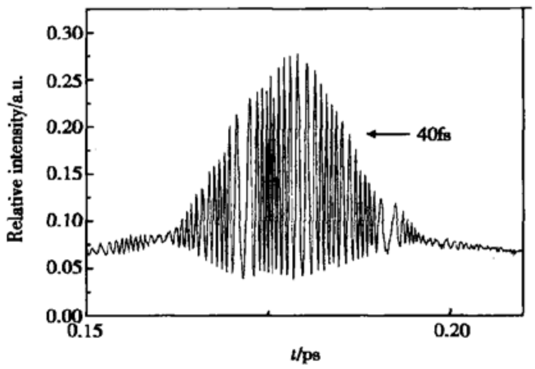

Fig. 5 Interferometric autocorrelation of a self-starting 40fs KLM pulse by the use of a Bragg mirror type of SESAM with low temperature method and surface state method combined absorber

the pulse duration is 40fs. Figure 6 shows the corresponding spectrum of modelocked Ti∶Al_2O_3 laser. The FWHM of spectrum is about 56nm, which can support the modelocking with pulse duration below 20fs.

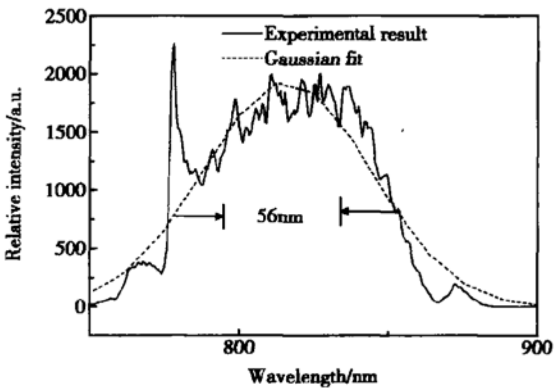

Fig. 6 Corresponding spectrum of the stable femtosecond pulses

4 Conclusion

We have reported a novel SESAM with low temperature and surface state absorber grown by MOCVD, with which we can achieve continuous wave mode locking in a diode-end-pumped Ti∶Al_2O_3 self-start Kerr lens modelocking laser. The reflection bandwidth of the SESAM is 30nm and the spectrum bandwidth is 56nm, which means that it supports the modelocking of 20fs. The pulse duration we got is 40fs and the frequency is 97.5MHz. The average output power is 300mW at the pump power of 4.45W.

References

[1] Sutter D H, Steinmeyer G, Gallmann L, et al. Sub-6-fs pulses froma SESAM-assisted Kerr-lens mode locked Ti: sapphire laser: at the frontiers of ultrashort pulse generation. Opt Lett, 1999, 24(9): 631

[2] Zhang Bingyuan, Li Gang, Chen Meng, et al. Passive mode locking of a diode end pumped Nd∶$GdVO_4$ laser with a semiconductor saturable absorver mirror. Opt Lett, 2003, 28(19): 1829

[3] Cho S H, Kärtner F X, Morgner U, et al. Generation of 90-nJ pulses with a 4-MHz repetition-rate Kerr-lens mode-locked Ti: Al_2O_3 laser operating with net positive and negative intracavity dispersion. Opt Lett, 2001, 26(8): 560

[4] Keller U, Miller D A B, Boyd G D, et al. Solid-state low-loss intracavity saturable absorber for Nd: YLF lasers: an A-FP-SA. Opt Lett, 1992, 17(7): 505

[5] Zhang Zhigang, Nakagawa T, Takada H, et al. Low-loss broadband semiconductor saturable absorber mirror for mode-locked Ti: sapphire lasers. Opt Commun, 2000, 176, 171

[6] Tsuda S, Knox W H, De Souza E A, et al. Low-loss intracavity AlAs/AlGaAs saturable Bragg reflector for femtaecond mode locking in solidstate lasers. Opt Lett, 1995, 20(12): 1406

[7] Wang Yonggang, Ma Xiaoyu, Li Chunyong, et al. Passive modelocked diode-end-pumped Nd: YAG with semiconductor saturable absorption mirror grown by metal organic chemical vapor deposition. Chin Phys Lett, 2003, 20(11): 1960

[8] Wang Yonggang, Li Chaoyang, Ma Xiaoyu, et al. Passive *Q* switching of flash-pumped Nd: YAG laser with ion-implanted GaAs. Chinese Journal of Semiconductors, 2004, 25(2): 148

[9] Brovelli L R, Jung I D, Kopf D, et al. Self-starting soliton modelocking Ti: sapphire laser using a thin semiconductor saturable absorber. Electron Lett, 1995, 31(4): 287

[10] Fluck R, Jung I D, Zhang G, et al. Broadband saturable absorber for 10-fs pulse generatin. Opt Lett, 1996, 21(10): 743

用 800nm 表面态方法和低温方法结合吸收区的半导体可饱和吸收镜实现掺钛蓝宝石激光克尔镜锁模

王勇刚[1]　马骁宇[1]　曹士英[2]　张志刚[2]

(1 中国科学院半导体研究所, 北京　100083)

(2 天津大学精密仪器与光电子工程学院 超快激光实验室, 天津　300072)

摘要: 研制了一种新型的 800nm 布拉格反射镜型半导体可饱和吸收镜, 其吸收区是低温方法和表面态方法相结合. 用该吸收体实现了氩离子激光器泵浦的掺钛蓝宝石激光器被动锁模, 脉冲宽度达到 40fs, 光谱带宽为 56nm, 后者意味着它可以支持 20fs 的锁模. 脉冲序列的重复率为 97.5MHz, 泵浦源为 4.45W 下平均输出功率为 300mW.

关键词: 半导体可饱和吸收镜; 表面态; 低温; 布拉格镜

EEACC: 4330B

中图分类号: TN389　　**文献标识码:** A　　**文章编号:** 0253-4177(2004)10-1233-05

2004-01-05 收到, 2004-04-02 定稿