Efficient Terahertz Radiation Generation from a Bulk InAs Mirror as an Intracavity Terahertz Radiation Emitter

2000 Jpn. J. Appl. Phys. 39 L366

(http://iopscience.iop.org/1347-4065/39/4B/L366)

Jpn. J. Appl. Phys. Vol. 39 (2000) pp. L 366–L 367
Part 2, No. 4B, 15 April 2000

Efficient Terahertz Radiation Generation from a Bulk InAs Mirror as an Intracavity Terahertz Radiation Emitter

Zhenlin LIU, Shingo ONO*, Hideyuki OHTAKE, Nobuhiko SARUKURA,
Tze-An LIU[1], Kai-Fung HUANG[2] and Ci-Ling PAN[1]

Institute for Molecular Science (IMS), Myodaiji, Okazaki 444-8585, Japan
[1]*Institute of Electro-Optical Engineering, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 30010, Taiwan*
[2]*Department of Electrophysics, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 30010, Taiwan*

(Received February 3, 2000; accepted for publication February 25, 2000)

Terahertz (THz) radiation is generated efficiently from a bulk InAs mirror with a shallow incidence angle inside the cavity of a femtosecond, mode-locked Ti:sapphire laser self-started by a strained saturable Bragg reflector. A magnetic field is also applied to the InAs mirror to enhance THz radiation.

KEYWORDS: intracavity, THz-radiation emitter, strained saturable Bragg reflector

Various practical applications using terahertz (THz) radiation have enabled revolutionary expansion over recent years. Various types of imaging techniques and sensitive gas detection with THz radiation will become widely accepted in the near future even for the industrial applications.[1,2] Before the opening of such new horizons, the THz-radiation source needs to be significantly improved in terms of power level, stability, compactness, and simplicity. The THz-radiation power from bulk InAs irradiated with femtosecond optical pulses is significantly enhanced and reaches 100 μW in a 1.7-T magnetic field.[3] We have also proposed a new method of generating THz radiation using an intracavity saturable Bragg reflector (SBR) in a magnetic field.[4,5] In this paper, we report a new configuration for generating THz radiation using a bulk InAs semiconductor mirror in a magnetic field as an intracavity emitter.

One approach for designing an intense THz-radiation emitter is the intracavity THz-radiation emitter scheme. Utilization of an intense intracavity laser optical pulse in this method will enable an efficient and simple THz-radiation emitter. We have examined SBR as an intracavity THz-radiation emitter, however, the performance of the total system was rather restricted due to the inflexibility of the SBR design.[3] In contrast, most optical materials are known to have high reflectance for s-polarization light. If the bulk InAs sample has a sufficiently high reflectivity, it will be a simple and flexible emitter that can be used in a mode-locked laser cavity. The reflectivity dependence on the incidence angle of the bulk InAs mirror is shown in Fig. 1. The InAs sample was found to have sufficiently high reflectivity for such an application with a shallow incidence angle for s polarization.

The femtosecond, mode-locked laser cavity with an intracavity THz-radiation emitter for demonstrating this concept is depicted in Fig. 2. The mode-locking is self-started by a strained saturable Bragg reflector (SSBR).[6] An additional Ti:sapphire crystal was introduced to the laser cavity as an intracavity amplification module[7,8] to induce higher excitation power of femtosecond optical pulses. An intracavity continuous-wave (cw) amplifier was introduced to compensate for the rather high loss due to the various intracavity components.[7] The laser cavity consisted of two 1-cm Brewster-cut Ti:sapphire rods. The Z-folded cavity contained two 10-cm and 20-cm radius-of-curvature folding mirrors to focus the intracavity laser beam to the main and amplification Ti:sapphire crystal rods, respectively. The main Ti:sapphire crystal was pumped using a 10-W solid-state

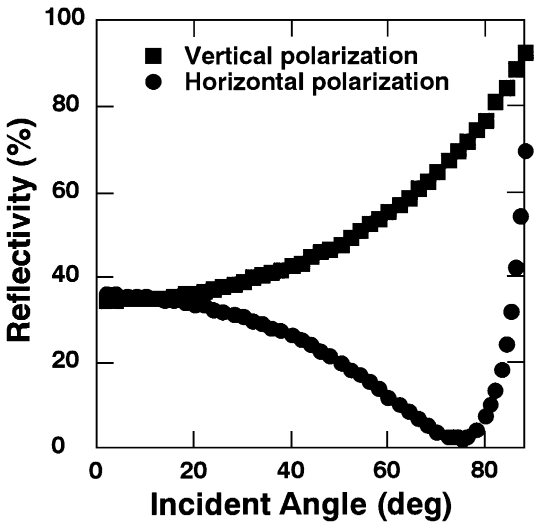

Fig. 1. Reflectivity dependence on the incidence angle of the bulk InAs mirror.

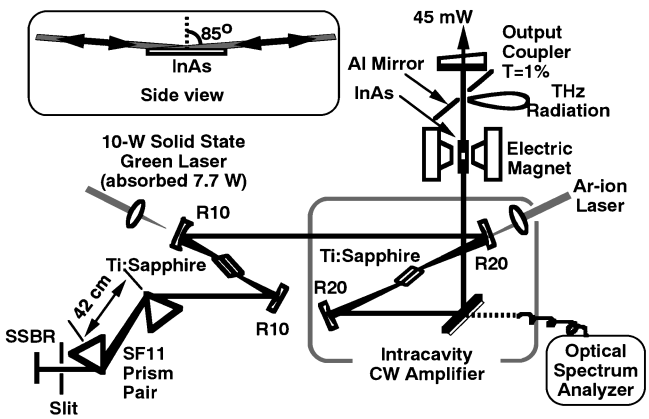

Fig. 2. Experimental setup of a bulk InAs mirror in a magnetic field for use as an intracavity THz-radiation emitter in a femtosecond, mode-locked Ti:sapphire laser self-started by an SSBR without focusing. An intracavity cw amplifier was introduced to increase the power inside the cavity.

*E-mail address: shingo@ims.ac.jp

green laser. The separation of a pair of SF11 Brewster prisms was tuned to about 42 cm for the intracavity dispersion compensation. The SSBR, as the saturable absorber for self-starting mode-locking, was placed at the end mirror position of the dispersion-compensation arm. A slit was put between the SSBR and the adjacent prism for tuning and stabilizing the wavelength. An output coupler with 1% transmission was used to monitor the laser condition. With a 10-W green laser pumping the main rod and a 5-W argon-ion laser pumping the amplifying rod, the output power was 45 mW, resulting in a power of 4.5 W inside the laser cavity. The repetition rate of the mode-locked pulses was 68 MHz. The autocorrelation trace and the spectrum were monitored with a rapid-scanning autocorrelator and an optical spectrum analyzer. Assuming a sech^2 pulse shape, 170-fs pulses were obtained with a 4.3-nm spectral width at 796 nm, yielding a nearly transform-limited time and bandwidth product of 0.35.

The laser beam inside the cavity is horizontally polarized, so the InAs sample was positioned so as to reflect the beam in the vertical plane so that the incidence beam on the sample has s polarization. The incidence angle of the laser beam on the bulk InAs mirror is about 85 degrees, and the estimated loss for the single reflection is 15%. An InAs sample of 30 mm $\times$ 10 mm was placed in the center of a compact electromagnet that can be tuned from 0 T to about 1 T. The THz-radiation detection system is the same as that used in ref. 4. The THz radiation was reflected at 45 degrees by an aluminum mirror with a 2-mm-diameter hole to allow the laser beam to pass through it. Two parabolic aluminum mirrors were used to continue to guide the THz-radiation beam directly to the InSb bolometer to detect the THz-radiation power or to the Fourier-transform polarizing interferometer to measure the THz-radiation spectrum. The magnetic-field quadratic dependence of the THz-radiation power was observed, as shown in Fig. 3. The average power of THz radiation was 5 nW. The spectrum of the THz radiation that peaked at approximately 0.4 THz was obtained by Fourier transformation of the autocorrelation of the THz radiation from a polarizing Michelson interferometer, as shown in Fig. 4. The interferometer was evacuated to avoid the possible absorption of water vapor in the air. Improving the cavity loss will significantly increase the output power level of THz radiation.

In conclusion, we have demonstrated a new intracavity THz-radiation generation scheme using an intracavity bulk InAs semiconductor mirror in a magnetic field. The advantages of this scheme are the simple emitter structure and its applicability to other media.

The authors are grateful for the support of the National Science Council of China under various grants. This research was partially supported by a Grant-in-Aid for Scientific Research on Priority Areas (No. 11231204) and a Grant-in-Aid for Encouragement of Young Scientists (No. 10750038) from the Ministry of Education, Science, Sports and Culture, NEDO Japan Small and Medium Enterprise Corporation, Creative and Fundamental R&D Program for SMEs, Research Foundation for Opto-Science and Technology, and a Sasakawa Scientific Research Grant from the Japan Science Society.

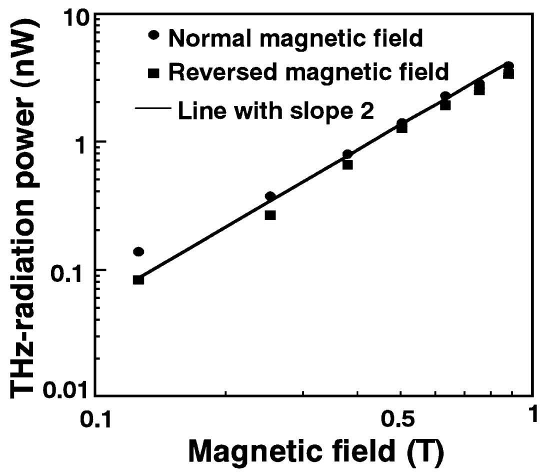

Fig. 3. Magnetic-field dependence of THz-radiation power. The circle and square indicate the normal polarity and reversed polarity of the magnetic field, respectively. The slope of the solid line is 2.

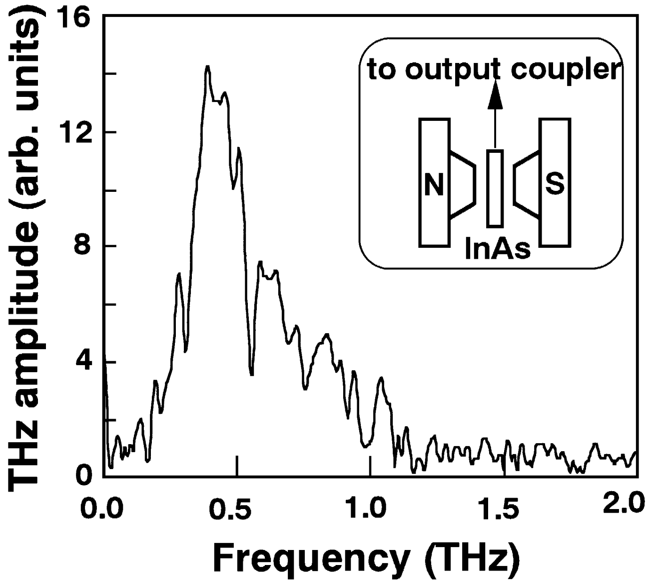

Fig. 4. THz-radiation spectrum from intracavity InAs in a 0.88-T magnetic field obtained by Fourier transformation of the autocorrelation from a polarizing Michelson interferometer.

1) D. M. Mittleman, S. Hunsche, L. Boivin and M. C. Nuss: Opt. Lett. **22** (1997) 904.
2) Z. Lu, P. Campbell and X.-C. Zhang: Appl. Phys. Lett. **71** (1997) 593.
3) N. Sarukura, H. Ohtake, S. Izumida and Z. Liu: J. Appl. Phys. **84** (1998) 654.
4) N. Sarukura, H. Ohtake, Z. Liu, T. Itatani, T. Sugaya, T. Nakagawa and Y. Sugiyama: Jpn. J. Appl. Phys. **37** (1998) L125.
5) T.-A. Liu, K.-F. Huang, C.-L. Pan, Z. Liu, S. Ono, H. Ohtake and N. Sarukura: Jpn. J. Appl. Phys. **38** (1999) L1333.
6) J. M. Shieh, T. C. Huang, K. F. Huang, C. L. Wang and C. L. Pan: Opt. Commun. **156** (1998) 53.
7) Z. Liu, S. Izumida, S. Ono, H. Ohtake and N. Sarukura: Appl. Phys. Lett. **74** (1999) 3622.
8) T.-A. Liu, K.-F. Huang, C.-L. Pan, Z. Liu, H. Ohtake and N. Sarukura: Jpn. J. Appl. Phys. **38** (1999) L1109.