Tunable Continuous-Wave Terahertz Generation/Detection Modules Based on Photonic Devices

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Abstract

We demonstrate the several different type of beating sources based on photonic devices. Broadband antenna integrated low-temperature-grown InGaAs photomixers are also verified for widely tunable continuous-wave THz generation and detection. The optimized performance depends not only on the characteristics of photonics devices but also module configuration.

Keywords : CW Terahertz Semiconductor Laser Photomixer

1. Introduction

Over the past decades, significant progresses have been realized in the fields of THz time-domain spectroscopy (TDS) and frequency-domain spectroscopy (FDS) using optical devices, photoconductive switch (PCS) and photomixer, respectively. Due to the unique properties of the THz wave, the THz technologies are now applied to the imaging, sensing, and spectroscopy fields for the applications of security, agriculture, environment, and medicine [1]-[2]. Researches on both the PCSs and the photomixers have been mainly conducted using the low-temperature-grown GaAs due to its short carrier lifetime and high resistivity. Recently, there have been several reports on LTG-InGaAs or ion-implanted (IM) InGaAs that can act as a photoconductive material aiming at the connection between the THz and the well developed InP-based communication technologies. In many cases of THz applications, the frequency-tunable continuous-wave (CW) operation of the radiation source with compact size and low cost is preferable. Up to now, the most promising candidate as a handheld and widely-tunable CW THz emitter is the combination of a photomixer and an optical beat source [3].

In this paper, we demonstrate stable widely tunable THz optical beating sources using a photonic device which include the antenna integrated wideband OE converter.

2. Experiments

A. Beating sources

Various semiconductor dual-mode lasers have been recently studied for the compact and low-cost optical beat source for THz photomixing. Although those devices show a stable dual-mode operation by two longitudinal modes in a single cavity, they have a limitation in tuning the mode beat frequency which corresponds to the wavelength difference between two longitudinal modes. Especially multisection DFB LDs based on strong gain-coupled grating shows superior characteristics to other devices even though it has limited tuning range. We demonstrate a novel monolithic dual-mode DFB laser operating in the 1550-nm range using all-active multisection structure with precise and broad-range wavelength tuning. Each wavelength of the two modes can be independently tuned by adjusting currents in micro-heaters (μ-heaters) which are fabricated on the top of the each DFB section. The DML structure as shown in Fig. 1 does not have a passive waveguide because of adopting an all-active structure.

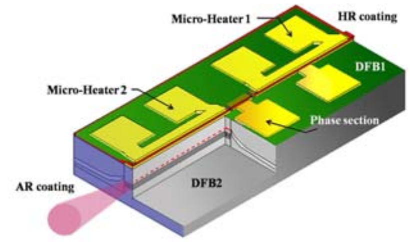


Fig. 1. Device structure of the dual-mode laser diode (DML).

The fabricated DML when a reverse bias applied to the phase section shows the SMSR and the initial wavelength difference are 34.4 dB and 1.7 nm, respectively. We successfully demonstrated the continuous tuning of wavelength difference from 0.81 nm to 4.7 nm using our invented original version of DML. In order to extend tuning range, we proposed a detuned DML as shown in Fig.1 which is similar to its original version of DML just except the period of each Bragg wavelength. To realize this detuned DML, we utilize not a conventional holographic system but a commercial e-beam lithography system. The all-active structure of our detuned DML provides us with easy fabrication steps as well as stable operation of DFB LDs. The continuous tuning of wavelength difference from 2.1 nm to 8.5 nm is successfully demonstrated in detuned DML. It covers optical beat frequency from 2.4 nm (0.3 THz) to 9.3 nm (1.15 THz) as shown in Fig. 2. The details about the device structure, fabrication, and basic characteristics of detuned DML were reported elsewhere [4].

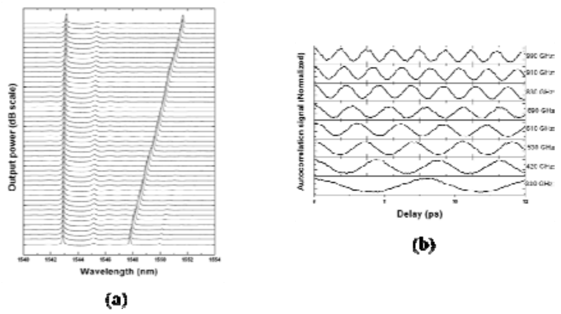


Fig 2. (a) Mode tuning result of detuned DML, (b) autocorrelation traces of the Detuned DML.

Dual-wavelength fiber lasers are another promising candidate for the compact and low-cost optical beat source to obtain wide tuning range of CW THz radiation. The EDF laser has the distinct characteristics of the homogeneous gain broadening and multi-longitudinal-mode oscillation. Firstly, the homogeneous gain broadening causes the wavelength gain competition in the EDF lasers. Therefore, the dual- or multi-wavelength lasing in the EDF lasers is not easy to be achieved even at room temperature. Recently, we propose a stable and widely tunable dual-wavelength operation in Er^{3+}-doped fiber laser using FBGs and FP-LDs as shown in Fig. 3. The continuous tuning of the wavelength spacing is achieved from 3.2 nm to 9.6 nm [5].

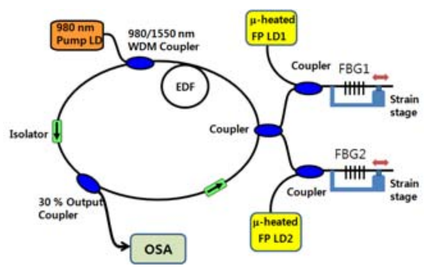


Fig. 3. Configuration for dual wavelength operation based on fiber laser.

B. InGaAs Based Photomixer

Recently, there have been several reports on LTG-InGaAs and ion-implanted (IM) InGaAs that can act as a photoconductive material aiming at the connection between the THz and the well developed InP-based 1550-nm communication technologies [6]. However, the InGaAs-based photomixers have the critical problem of low dark resistance (*i.e.* high dark current), which is not acceptable for efficient THz emission because of background thermal radiation as well as low thermal damage threshold. Consequently, the reported THz powers from InGaAs-based photomixers are several ten times lower than those from typical LTG-GaAs photomixers. Therefore, more thorough studies on the active optimizations would be needed for achieving more efficient and widely-tunable InGaAs-based photomixers.

For the fabrication of the LTG-InGaAs photomixers, 1.2-µm-thick Be-doped InGaAs layers were grown on semi-insulating InP substrates around 220°C by using a molecular beam epitaxy (MBE) system. Log-spiral antenna was integrated on InGaAs layer using stepper system. Si lens was attached to photomixer for extracting collimated THz wave. A characteristic of the fabricated broadband LTG-InGaAs photomixer is shown in Fig. 4.

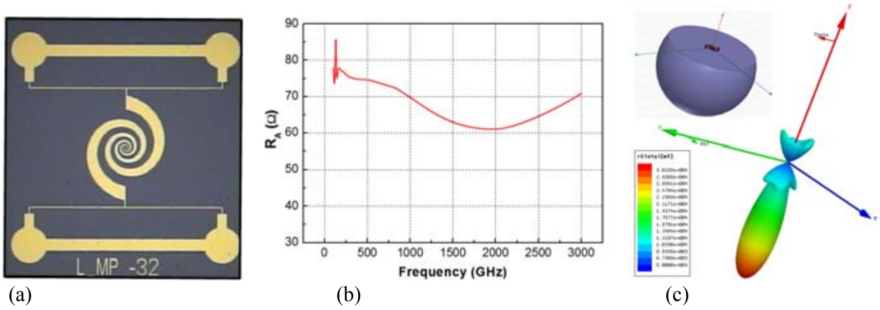


Fig. 4. (a) SEM images of the log spiral antenna, (b) Input impedance simulation results of the log spiral antennas, (c) radiation pattern.

Any other regions of the photoconductive switch have been removed for reducing dark currents of the fabricated photomixer. THz antenna and the interdigitated-finger patterns were simultaneously defined on the mesa structure photoconductive switch by using a stepper system followed by the evaporation of Ti (100 Å) and Au (2500 Å). Finally, a 200-nm-thick SiNx layer was deposited covering the mesa region for anti-reflection coating. Fig. 5 shows our developing compact fiber-coupled photomixer module. It consists of a cylindrical body made of stainless steel, an high-resistivity hyper-hemispherical Si lens, a photomixer chip bonded on a ring-shaped PCB with a hole in the center by using the flip-chip bonding technique, and a fiber assembly which is assembled an optical single mode fiber (SMF) and an aspherical lens for free-space coupling the SMF to the active area of the photomixer chip. Using the laser welding process we have successfully combined the photomixer module with the fiber assembly. DC bias is applied by a small-sized electric coaxial cable connected to the PCB, but not shown in Fig. 5.

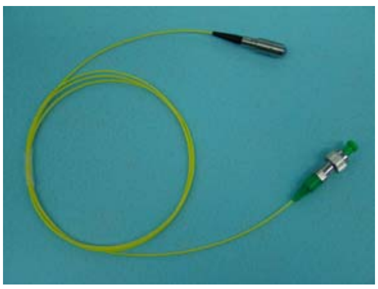
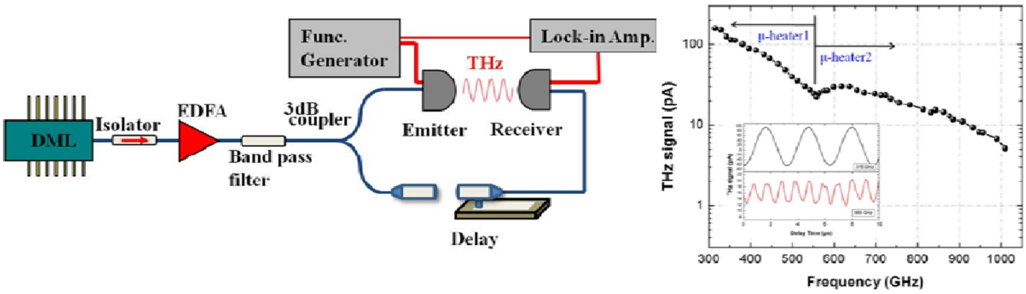


Fig. 5. Compact fiber-coupled photomixer module combined the photomixer module with the fiber assembly by using the laser welding process.

3. Tunable CW THz Generation

A fiber-coupled CW THz system was composed as shown in Fig. 6(a). The optical beat signal emitted from the detuned DML package was amplified by an EDFA. An emitter and a receiver made of our LTG-InGaAs photomixer were used to generate and detect THz signals, respectively. In order to enhance the detection sensitivity, we used a lock-in amplifier and a sine-wave function generator.



(a) (b)

Fig. 6. (a) CW THz measurement setup, (b) Frequency tuning characteristic of THz emission from LTG-InGaAs photomixers illuminated by the detuned DML.

CW THz radiation using detuned DML and LTG-InGaAs photomixer was shown in Fig. 6(b). THz radiations in the low-frequency region are generated by reducing the wavelength difference between lasing modes of the detuned DML via current injection into μ-heater only.

4. Summary

We successfully demonstrate the continuous-wave (CW) THz system based on photonics devices. The continuous frequency tunings of the CW THz emission from 0.315THz to over 1 THz have been also successfully achieved using the LTG-InGaAs photomixers.

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Acknowledgments

This work was supported by Joint Research Project of ISTK and the Public welfare & Safety research program through the National Research Foundation of Korea (NRF), by the Ministry of Education, Science and Technology- grant #2010-0020822 and also by the NRF of Korea- grant # 2007-00011.