Optical generation of Terahertz based on all fiber highly coherent optical parametric light source

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***Abstract*—Narrow band Terahertz generation based on an all fiber, highly coherent pump light source derived from fiber optical parametric process is reported. A pair of phase conjugated beams with high coherence and narrow bandwidth are generated via all fiber parametric process as the seed light. The amplified highly coherent light beam is injected into DSTMS to stimulate the emission of Terahertz radiation. A terahertz wave with the frequency of 1.25 THz and linewidth less than 512 MHz is generated.**

I. INTRODUCTION

TERAHERTZ radiation has been attracting comprehensive attentions and interests in the past years since it has many potentials in a variety of fields, ranging from fundamental science through to practical applications [1,2]. The efficient generation of radiation in terahertz frequency range 0.3~10 THz is the principal problem that must be solved. Terahertz generation via optical method can cover nearly the entire terahertz gap [3]. The usual terahertz source based on optical method rely on bulky and expensive solid state laser source [4]. This kind of Terahertz sources is adapted well with the laboratory environment but the practical applications require to use a kind of compact and cost cost-effective Terahertz source. Based on this point, the adoption of a cost-effective all fiber laser pump source in terahertz generation is considered as a true milestone [4].

Among a variety of optical methods, optical difference frequency generation is a promising technique for the realization of widely tunable, narrow-bandwidth terahertz radiation [5,6]. The difference frequency process is happened via a nonlinear crystal illuminated by a dual-wavelength laser or simply two light beams from two lasers. However, the low coherence of the pump light leads to low conversion efficiency [7]. Thus a pair of highly coherent light sources with arbitrarily optional frequency difference in an all fiber configuration would be of great significance for difference frequency generation of terahertz with a compact dimension [4].

In this paper, we demonstrate the generation of terahertz from the difference frequency process pumped by an all fiber, highly coherent light source based on fiber optical parametric process. A pair of ultra-narrow bandwidth light beams are generated during the optical parametric amplification (OPA). Due to the high coherence and ultra-narrow bandwidth of the pump light pair, it can generate ultra-narrow bandwidth terahertz wave in the difference frequency process. The frequency of generated terahertz wave is 1.25 THz and its bandwidth is less than 512 MHz.

To the best of our knowledge, this is the first demonstration of terahertz generation pumped by an all fiber, highly coherent parametric light source. It is a compact and cost-effective THz-radiation system.

II. EXPERIMENTAL SETUP AND RESULTS

The schematic diagram of the experimental setup is shown in Fig.1. Before the difference frequency process, an all fiber highly coherent parametric light source is built up. In order to obtain high peak power for the succedent difference frequency process, the pulsed pump scheme is adopted. A homemade ultra-narrowband picosecond mode locked fiber laser is built up as the seed light for the pump of the succedent OPA. Traditionally, mode locked fiber lasers are featured as broad spectral bandwidth [8]. In order to get ultra-narrow bandwidth terahertz, an ultra-narrow spectrum from the mode locked fiber laser is required. Here, a homemade fiber Bragg grating with the spectral linewidth of 0.1 nm is fabricated and inserted as an intra-cavity filter to restrict the oscillating longitudinal modes. In order to get the low repetition rate, ultra-long cavity is used by inserting some low dispersion fiber. And fine intra-cavity dispersion management is needed to ensure low net dispersion.

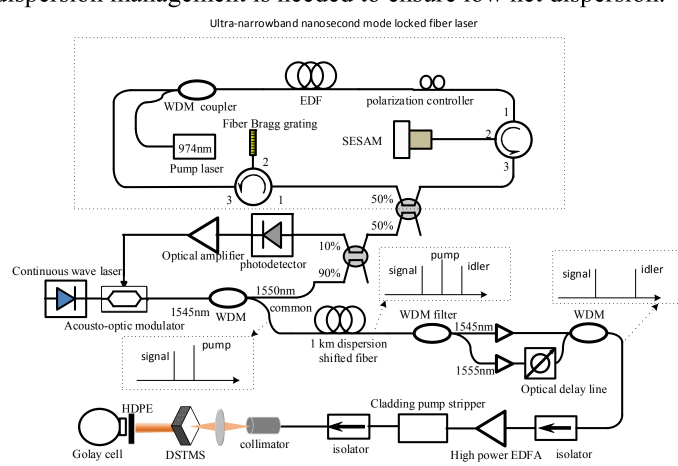
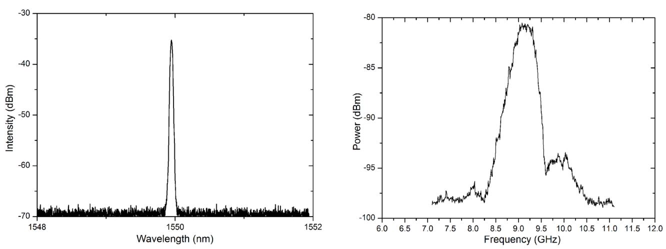


Fig. 1. Experimental setup of terahertz generation pumped by the all fiber highly coherent optical parametric light source.

A stable pulse train with center wavelength of 1549.9 nm is generated from the mode locked fiber laser with the repetition rate of 848 KHz, pulse width of 650 ps and linewidth of only 512 MHz measured by a heterodyne method, as shown in Fig. 2 (b). One kilometer dispersion shifted fiber (DSF) is used for parametric amplification to generate amplified signal and the corresponding idler [9]. The generated pulse is divided into two parts via a 10/90 optical coupler. The 90% part is amplified by an EDFA and injected into the DSF to act as the pump of OPA. The 10% pump is detected by the photodetector (PD) to be translated into electric signal. And a continuous wave (CW) light at 1544.9 nm is modulated by the detected electric signal via an acoustic-optic modulator to generate the synchronized signal. The signal pulse at 1544.9 nm and pump at 1549.9 nm are combined and injected into the DSF via a wavelength division multiplexing (WDM) coupler. Due to the parametric process, the amplified signal at 1544.9 nm and newly generated idler at 1554.9 nm are obtained at the output of the DSF. The residual pump and higher order four wave mixing sidebands are rejected. And only the phase conjugated signal and idler are reserved as the seed source by an all fiber WDM filter. The simultaneous generation of the signal and idler photons during the parametric process indicates that each photon pair is correlated in the quantum sense [10]. Hence the generated signal and idler pair is the perfect seed light for the pump of the succedent difference frequency process. The polarization states of both the signal and idler are adjusted by polarization controller. The seed source is amplified via a high power EDFA and launched into free space via a collimator. The output beam is focused on a piece of DSTMS crystal via a lens. The generated terahertz emission is detected by a Golay cell, while a high density Polyethylene is placed in between to prevent any light emission from reaching the Golay cell.



(a) (b)

Fig. 2. Output spectrum of the mode locked fiber laser (a). Electric spectrum by heterodyne method (b).

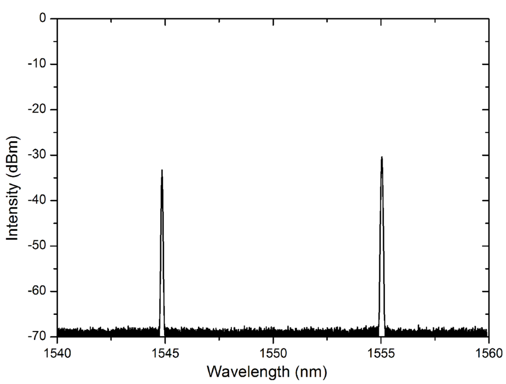


Fig. 3. Optical spectrum of the phase conjugated signal and idler.

The spectrum of the eventual phase conjugated signal and idler is shown in Fig. 3. Due to the phase conjugation between the signal and the idler, high coherence between the two wavelengths exists. It should be noted that the respective polarization states of the signal and idler are critical to the conversion efficiency of the difference frequency process. The polarization states of the signal and idler are finely adjusted so as to maximize the generated terahertz power. The combined signal and idler are amplified to be 30 dBm and incident on the DSTMS crystal. The measured terahertz power is 320 nW. The terahertz frequency can be calculated from the frequencies of signal and idler to be 1.25 THz. When the difference frequency crystal DSTMS is removed and the high power light is incident directly on the HDPE, however, no power is observed. The advantage of our proposed scheme is that the generated terahertz wave has very narrow spectral bandwidth. Theoretically, the difference frequency procedure happens primarily between the respective spectral center of the signal and idler wavelengths. Thus the spectral bandwidth of the generated terahertz wave should be less than the original signal and idler bandwidth. Benefiting from the ultra-narrow bandwidth from the mode locked fiber laser, the bandwidth of the terahertz should be less than 512 MHz. Limited by the conversion efficiency curve of the DSTMS crystal [11], the power of the generated terahertz can be increased significantly if higher frequency terahertz is generated.

III. SUMMARY

In conclusion, we propose a terahertz source based on difference frequency generation pumped by an all fiber highly coherent parametric light source. An ultra-narrow bandwidth long cavity mode locked fiber laser is built up as the pump for the fiber optical parametric process. A pair of phase conjugated signal and idler light beams are generated with very narrow bandwidth. The terahertz wave is generated with the frequency of 1.25 THz and linewidth less than 512 MHz via the succedent difference frequency process.

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