A Novel Fiber-based Terahertz Source

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Abstract—**One kind of novel fiber-based Terahertz source -- opt-THz fiber is proposed, it is based on the second order nonlinearity in the poled optical fiber, where optical fiber is used to transmit optical pump power and distributely generate Terahertz fields while outside Terahertz fiber is used to transmit Terahertz wave. Simulations have been done and optimized designs are given.**

I. Introduction And Background

Terahertz (THz) means the Electro-magnetic wave with frequency from 100GHz to 10THz. Due to its special features; THz has attracted wide attentions, especially in the applications on security and biomedicine [1]. The output power of THz source is limiting the further commercialization for the THz system and its wider applications. Currently electronic THz emitter can emit relative higher power (up to a few hundreds mW) but with frequency lower than 1THz due to the "electronics bottle neck". While optical researchers use optical means: use high power and ultrafast laser to down-convert and emit/detect THz field. Compared with electronics means, here the emitted THz powers by optical means are much lower, from nano-watt to micro-watt, but with wider bandwidth which is necessary for the spectroscopy and sensing applications. Quantum cascaded laser (QCL) has the potential to emit high power and tunable THz frequency but QCL has to work under cryogenic temperature till now [2]. THz source have became a barrier for the THz technology, we are looking forward to the breakthrough of a room temperature operating, high power, wide band and frequency tunable THz source.

Besides the THz generation, coupling and THz field propagation are meeting a serious problem, we also need to investigate a waveguide to guide and propagate THz light in long distance. It is a trend to apply fiber technology in the THz areas [3]. So far, we haven't found any material which has low loss at THz band as compared to SiO_2 at 1550nm wavelength band. The high-resistance silicon, which is a low loss crystal material at THz band, has an absorption coefficient of $0.05cm^{-1}$ at THz band, which is almost 22dB/m, This is unbelievable for optics, but this is facts at THz band. THz field has lowest loss in the air with a loss of around 0.1dB/m. Therefore THz fiber should try to confine more THz fields in the air [4], e.g. by using ring design with hollow core, in order to reduce loss.

Combine the above all ideas of optical fiber and Terahertz fiber and Terahertz source, we propose a new Opt-THz fiber source which has a optical fiber in the center to transmit high energy optical pump while outside THz ring waveguide can guide and propagate THz wave, the nonlinearity of optical fiber core are also enhanced by poling effect in order to distributely and efficiently generate THz fields through Different frequency (DF) effect.

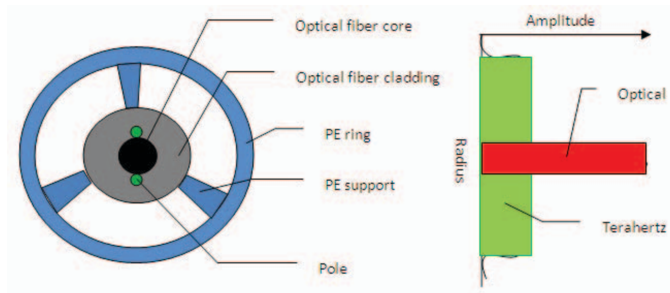

Fig.1 Cross profile of the proposed opt-THz fiber

II. THz fiber design & Simulations

As the waveguide to transmit high energy optical pump, a multimode optical fiber design should adopted, and fiber core will have a larger standard diameter of 62.5µm in order to transmit more power and reduce costs. Optical cladding has an outer diameter of 125µm. Because optical fiber 's loss of 0.2dB/dB at 1550nm wavelength is much much lower than THz fiber's loss of a few dB/m, therefore in our design reducing THz loss is always put in the first priority.

With the ring design of THz fiber, THz fields will mostly distribute inside the ring which including both the optical fiber and the air portion, as shown in Fig.1. Increasing the air portion will reduce the THz loss. The size of the inner diameter of the PE ring will decide the THz pass band. For example, 300µm inner diameter will have a cutoff frequency of 200GHz approximately [6,7], and larger diameter will have even lower cutoff frequency.

Our final target is to design a fiber-based THz source. The THz generation mechanism is DF effect through second order nonlinearity. But it is well known that the second order nonlinearity coefficient is zero in the SiO_2 because SiO_2 molecular is symmetrical structure. Some methods have been used to generate higher 2^{nd} order nonlinearity, especially poling is a effective ways to realize it. Thermal poling and UV excited poling has reached electron-optic coefficient value of 6pm/v [8,9]. Although this nonlinear coefficient is still small, it is not a problem in the fiber because optical fiber provides a very long interaction distance. Although poling will inevitable increase the optical loss, but compared with current THz loss, it is still quiet low and can be ignored.

Due to the existence of higher THz loss, only when the THz gain is larger than the THz loss, then the THz field will be accumulated, amplified and transmitted. Optical pump power will also be decayed along the distance because energy will be converted to THz distributely, therefore the nonlinear DF effect will gradually decreased with the distance until a balanced point. The highest THz power is reached when the THz gain equals to THz loss, at this point is the optimized length of

opt-THz fiber. This value can be obtained by resolving three-wave nonlinear coupling equations [10, 11].

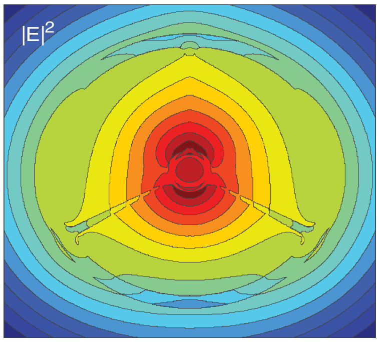

Fig.2 THz modal field distributions of the Opt-THz fibers

Figure 2 shows the THz modal field distributions of proposed Opt-THz fibers. The optical fiber has an outer diameter of 80μm, the diameter of THz polymer waveguide is 600μm. The THz frequency is set as 1THz, the refractive index of silica and polymer (HDPE) is 1.96 and 1.51 with material absorption coefficient 2.6 cm^{-1} and 0.3 cm^{-1} at 1THz[12]. The modal field confinement factor in air, silica, and polymer of ring Opt-THz fiber will be 0.66, 0.22 and 0.12, respectively. The absorption loss of guided mode due to material absorption in Opt-THz fiber can be qualified by:

$$\alpha_{ab} = \frac{\sqrt{\varepsilon_0 / \mu_0} \int_{background} n_b \alpha_m |E|^2 ds}{\left| \int_{all} \left(E \times H^*\right) \cdot \hat{z} ds \right|}$$

where α_{ab} is the modal absorption loss due to material absorption, while α_m is the bulk absorption loss of Opt-THz fiber materials. "bankground" and "all" represent the integrals over the background material region versus the entire fiber cross section. n_b is the refractive index of the background material. The estimated total material loss of ring Opt-THz fiber is about 0.613 cm^{-1} at 1THz frequency.

The modal absorption losses of proposed Opt-THz fibers are also shown in Fig. 3 with frequency range from 0.5 to 2 THz. It should be noticed that we assumed the absorption coefficient of silica to be constant 2.6 cm^{-1} in this case. Actually, the absorption coefficient will drop to 0.62 cm^{-1} at 1 THz. This observation will result in a decreased modal absorption loss at low frequency region (lower than 1 THz), for example, the total mode loss of ring Opt-THz fiber is about 0.025 cm^{-1} at 0.5THz.

It should be highlight that, the main loss mechanism at THz band in the air comes from water's absorption, so dehydration process and waterproof coating is very necessary for the package of the opt-THz fiber.

III. Conclusions

One kind of novel fiber-based Terahertz source has been proposed, it is based on the second order nonlinearity in the optical fiber, where poled optical fiber with higher 2nd nonlinearity is used to transmit optical pump power and distributely generate Terahertz fields along the fiber, while outside Terahertz fiber is used to transmit Terahertz fields. The maximum THz power will be reached at an optimized fiber length. It will provide guidance for the fabrication of the opt-THz fiber.

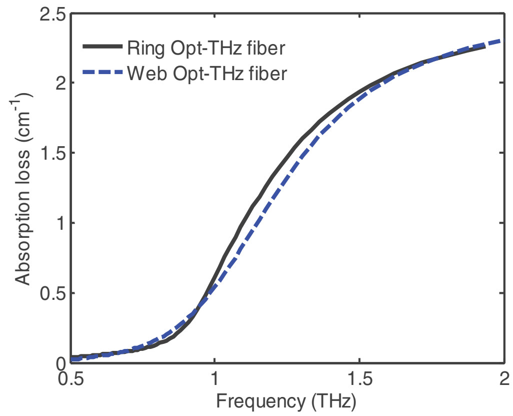

Fig.3 THz modal absorption loss of the Opt-THz fiber

Acknowledgement

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References

[1] A. Giles Davies, Andrew D. Burnett, Wenhui Fan, Edmund H. Linfield, and John E. Cunningham, "Terahertz spectroscopy of explosives and drugs ", Material today, vol.11(3), pp.18-26, (2008)

[2] Benjamin S. Williams, Terahertz quantum-cascade lasers, Nature Photonics Vol. 1, 517 - 525 (2007)

[3] Yandong Gong, M.Y.W. Chia, B. Luo, "Terahertz Spectroscopy Technology Trend Using 1550nm Ultrafast Fiber Laser," Microwave and Optical Technology letters, vol. 49(2), pp. 439-443, (2007)

[4] Guobin Ren, Yandong Gong, Ping Shum, *et al*, "Low-loss Air-core Polarization Maintaining Terahertz Fiber," Optics Express, vol. 16(18), pp. 13593-13598, (2008)

[5] Daru Chen, Haibin Chen. "A novel low-loss Terahertz waveguide: Polymer tube." Optics Express, Vol.18, No.4, pp3762—3767, (2010)

[6] Matthias C. Hoffmann, Ka-Lo Yeh, Janos Hebling and Heith A.Nelson. "Efficient terahertz generation by optical rectification at 1035nm." Optics Express, Vol.15, No.18, pp11706-11713, (2007)

[7] Daru Chen, Haibin Chen. "A novel low-loss Terahertz waveguide: Polymer tube." Optics Express, Vol.18, No.4, pp3762—3767, (2010)

[8] Peter G.Kazansky, Philip St.J.Russel and Hiromichi Takebe. Glass fiber poling and applications. Journal of Lightwave Technology, Vol.15, No.8, pp1484-1493, (1997)

[9] Simon Flemming, Danny Wong, Hugh Inglis, Wei Xu, et al. Poled fibre devices for Electro-Optic modulation, Proceeding of SPIE, Vol.2893, pp450-460, (1996)

[10] Govind P. Agrawal, "Nonlinear fiber optics". 3rd version. Academic Press, (2001)

[11] Zhichao Ruan, Georgios Veronis, Konstantin L. Vodopyanov, Marty M. Fejer1 and Shanhui Fan. Enhancement of optics-to-THz conversion efficiency by metallic slot waveguides, Vol. 17, No. 16, OPTICS EXPRESS 13502 (2009)

[12] Y. S. Jin,G. L. Kim, S.G. Jeon, "Terahertz dielectric properties of polymers," J. Korean Phys. Soc. 49 (2) 513-517, (2006)