Study of THz emission from ring-Airy beam induced plasma

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***Abstract*— We experimentally investigated the THz emission from two-color ring-Airy beam induced plasma in the ambient air. The results show that this exotic autofocusing beam tends to form an elongated weak filamentation with a main peak at the front and a 'tail' with certain oscillations following, which leads to a higher THz yield and a slightly narrower THz spectrum than the emission from a Gaussian beam plasma under the same circumstances.**

I. INTRODUCTION

THE family of abruptly autofocusing beams were theoretically proposed[1] and experimentally observed several years ago [2,3], after 1D and 2D Airy beams were reported in 2007 [4,5]. They are known for some unusual properties, such as the ability to autofocus with a parabolic trajectory and to abruptly increase the maximum intensity by orders of magnitude at the focus. The nonlinear propagation effect at the focus of ring-Airy beam has been demonstrated in the glass [6], and the air-plasma channel generated using ultra-intense 2D Airy beams has been studied [7], while the data of ring-Airy beam induced air plasma is still missing.

In the THz community, the development of table-top intense broadband THz source has always been a topic with great importance. One of the most efficient approaches is using two-color femto-second laser plasma [8,9]. Ever since this method was demonstrated, it has caused a substantial amount of discussion and people have tried to play with different parameters of plasma to improve the generation efficiency.

It is believed that the great tunability of ring-Airy beam [3] and its wavepacket stability at nonlinear focus regime [6] make the plasma induced by this novel wave a promising broadband THz source with interesting potentials, such as in THz remote sensing spectroscopy [10].

In our experiment, the ring-Airy beam was generated by sending a 35fs, 50Hz, 800nm Ti-Sapphire laser beam to a Spatial Light Modulator (SLM) with a phase mask exerted on it . The unwanted zero-order in the center was blocked to give the ring-Airy distribution, see Fig.2(a). Since the beam was generated using a "phase-only" method without performing a Fourier Transform with a FT lens, the loss of large amount of energy in the zero-order was avoided, enabling the formation of plasma in the air, which requires a threshold intensity of 10^{12}~10^{13}W/cm^2 . For generation details please see Ref. [3] and [9]. We measured the THz waveform using free space electro-optical sampling with a 3-mm-thick ZnTe crystal. A pair of off-axis parabolic mirrors were used to collect and refocus the THz radiation from plasma, see Fig. 1. A CCD camera took the fluorescence images of the plasmas.

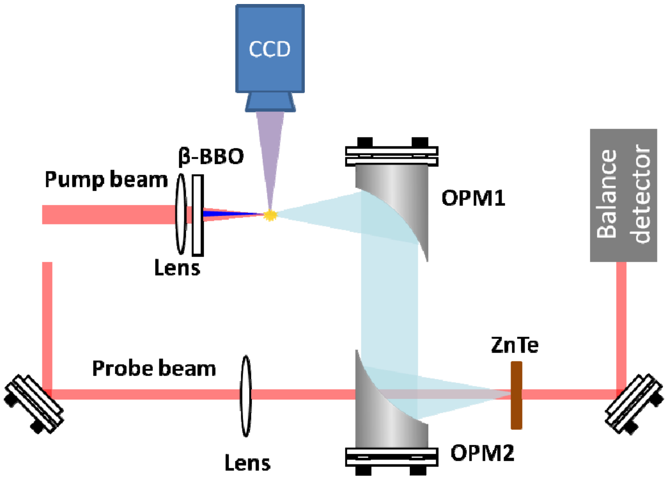

Fig. 1. Experimental setup, OPM: Off-axis Parabolic Mirror

II. RESULTS

In Fig.2(b), the fluorescence image comparison is shown between a two color ring-Airy beam plasma and a two color Gaussian beam plasma in the air. Both of the two beams were focused by a 100mm focal length lens followed by a 50-µm-thick β-barium borate (BBO). The pulse energy of the beams were both 0.65 mJ before the β-BBO. As we can see in the figures, he ring-Airy plasma has a relatively brighter peak in the front and followed with a dimmer "tail", which matches the fluorescence images of ring-Airy beam focused in the glass reported previously [6]. In comparison, the Gaussian plasma is about 3 times shorter in length and over 40 times brighter in FL than the ring-Airy plasma. Notice that the two beams focused at different locations. This phenomenon was well expected, considering the ring-Airy beam has autofocusing ability. The beam after the 100mm lens still follows a parabolic trajectory before it collapses at the focus, whereas for Guassian beam, the beam caustic after the lens is linear, leading to a small focus difference between the two beams. This was captured by the CCD and shown in the figure as real. No shifting along the z-axis (laser propagation direction) was done during the image processing.

In Fig.2(c) and (d), THz waveforms and the corresponding spectrums emitted from the two plasmas in Fig.2 (b) are plotted together. During the experiment, the lens location as well as the β-BBO angle and location were all optimized for each measurement to avoid the signal discrepancy caused by focus location changes and the second harmonic generation efficiency difference. When we did the integration over time on the square of the waveforms in Fig.2(c) in order to retrieve the THz pulse energy, we found that the THz pulse energy generated by the ring-Airy beams contains about 4.7 times the energy of the one by Gaussian, which is possibly due to the plasma length difference between the two beams [11]. At the same time, the ring-Airy THz emission has a center frequency slightly lower than the Gaussian one, which matches the fact that the Gaussian plasma has higher plasma density [12].

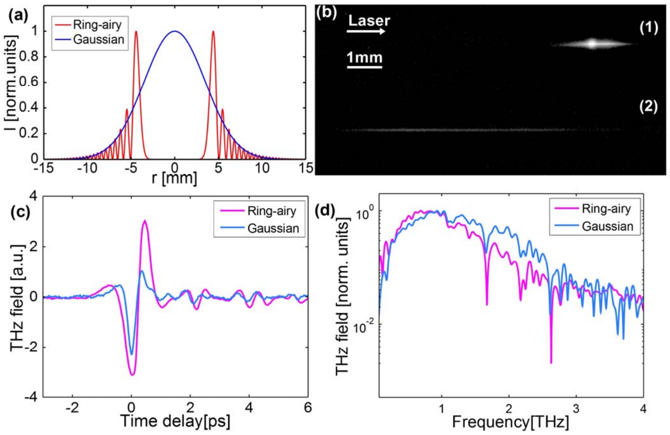

Fig. 2. (a) Schematic comparison between the radial intensity distribution of the ring-Airy and the Gaussian beam used in the experiment. (b) Fluorescence emission images of (1) Gaussian beam and (2) ring-Airy beam 2 color air-plasmas in grey color. The intensity is shown in a logarithmic scale to make both plasmas visible. (c) THz waveform generated by the ring-Airy plasma (pink) in comparison with the one generated by Gaussian plasma (blue). (d) Normalized THz spectrums emitted by the ring-Airy plasma (pink) in comparison with the one generated by Gaussian plasma (blue).

III. SUMMARY

In conclusion, we have shown the possibility of using ring-Airy beam to generate THz wave from laser-induced plasma in the ambient air, with a comparable efficiency as normal Gaussian beam. We measured that under the same experimental conditions, there is a small discrepancy between the THz pulse energy and spectrum generated by ring-Airy beam and Gaussian beam, possibly due to the length and electron density difference of the corresponding plasmas. We believe these results pave the way of extending ring-Airy beams as well as other exotic beams applications into THz frequency. It sets a very useful reference for the scientists who will explore using different novel wavepackets as THz sources in the future.

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