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The dependence of external focusing geometries and polarization in generation of supercontinuum by femtosecond laser pulse in air

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ABSTRACT

Supercontinuum (SC) generation in ambient air using different focusing geometries and laser energy under linear and circular polarization was investigated experimentally. Under the same input laser energy, the SC spectra in the visible range became wider when smaller f-number convex lens are used and the linearly polarized laser is used as the pump source, the main nonlinear mechanism for asymmetric spectral broadening of femtosecond laser pulses towards the higher frequencies in isotropic media is that the cascade generation with GHz spectral shift for gases and the four-photon parametric wave mixing processes. Besides, the temporal differential of electron density $N_e(t)$ play a more important role in extending the SC spectra to the blue side than the interaction length l. Under the same magnitude of the optical field and the critical power for self-focusing of linearly and circularly polarized beams, the SC spectra range is wider when circularly polarized beams as the pump source.

In air, intense femtosecond laser pulses undergo filamentation and able to propagate over a long distance due to the dynamic balance between Kerr induced self-focusing and plasma induced defocusing of the laser beam [1–5]. The filamentation becomes a unique source of broadening supercontinuum generation. The first investigation of SC in gases was carried out by Corkum and coworkers [6]. Since then, extensive efforts have been made on SC from femtosecond light filaments in air [7–12]. Supercontinuum emission spectra range generally covering from the UV to the mid-IR SC source and can be used as biomedical imaging [13], few-cycle femtosecond pulses generation [14], remote sensing [15–16], molecular fingerprint spectroscopy [17] and so on.

Generation of broadband SC light has been of great interest in recent years. Recently, Liu et al. studied the generation of the SC in air using tightly focused femtosecond laser pulses by changing the input laser energy and broadband white-light emission covering the whole visible spectral region was generated when the input laser energy up to 16.5 mJ [11]. Yang et al. found that the SC conversion efficiency was reported to be higher for circularly polarized light compared to that for linear polarized light when the incident laser intensity was very much higher than the breakdown threshold of air.

In this letter, we present experimental investigation of SC generation using f/3, f/4, f/6, f/8 and f/16 focusing geometries (corresponding focusing length is 75 mm, 100 mm, 150 mm, 200 mm and 400 mm), respectively. Under the same input laser

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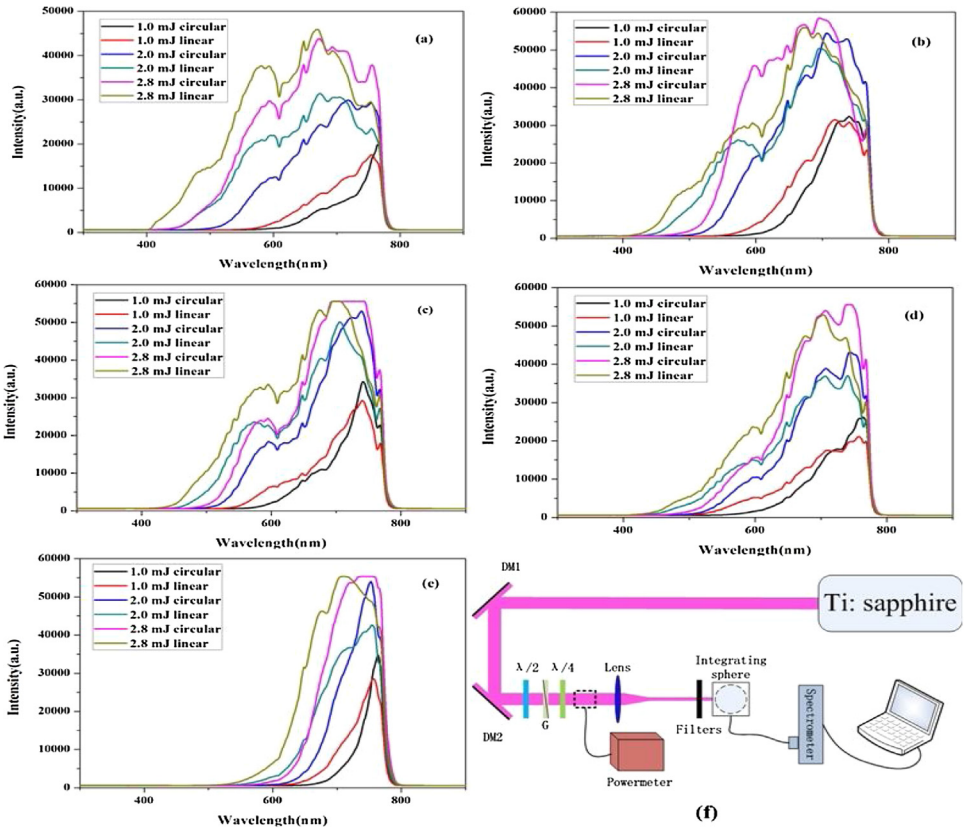

Fig. 1. SC spectra generated by different input laser energies and focusing lens under linearly and circularly polarized laser. (a) f/3 focusing geometry, (b) f/4 focusing geometry, (c) f/6 focusing geometry, (d) f/8 focusing geometry, (e) f/16 focusing geometry, (f) experimental setup, DM1 and DM2: 800 nm reflect dielectric mirrors, G: Glan laser polarizer.

energy, the SC spectra range become wider when smaller f-number convex lens used, besides, under the same input laser power and focusing geometry, the linearly polarized laser is more efficient in generating wider range SC.

The experiments were carried out using a one-box ultrafast Ti:Sapphire amplifier (Coherent Libra) with the wavelength of 800 nm, the width of 50 fs at the repetition rate of 1 kHz. As shown in Fig. 1(f), The laser energy is adjusted by the combination of a half-wave plate and a Glan laser polarizer, and a quarter wave plate of 800 nm is employed to change the polarization state of laser pulses. In order to avoid the influence of 800 nm laser pulse, the generated SC spectra is firstly pass through an array of 800 nm short pass filters, then an integrating sphere is placed behind the filters to get the full information of the SC spectra. The SC spectra is recorded by using a spectrometer (AvaSpec-ULS3648).

Fig. 1 shows the SC spectra generated by different incident laser energies from 1.0 mJ to 2.8 mJ and with different focusing geometries lenses. From Fig. 1(a)–(e), by increasing the input laser energy and decreasing the focal length of lens, the SC spectra range increased. The extension of the SC is as large as that described in earlier investigation where extension up to 400 nm was observed [11]. Besides, under the same incident laser energy, for all five different focal length convex lenses used in our experiment, the generated SC spectra range is wider when linearly polarized beams as the pump source.

In Fig. 1, the SC spectra broaden towards the short wavelengths, Four-Photon Parametric mixing (FFP) processes is one of the nonlinear mechanism, however, the FFP processes are symmetrical in respect to main wavelength. In addition to the FFP processes, another nonlinear mechanism is that the cascade generation with GHz spectral shift for gases [19]. According to Ref. [19], by combined jointly action of cascade GHz emission and FFP processes would lead to asymmetric spectral broadening towards the short wavelengths. The SC spectra range is become wider from Fig. 1(e)–(a), we attribute this to by reducing the focal length, the generated GHz emission is becoming stronger, the combined two nonlinear mechanisms continuously occurring, as a result, the SC spectra broadening towards the short wavelengths continuously.

As presented in former research [18], both the interaction length l and the temporal differential of electron density $N_e(t)$ have contribute to the SC spectra extend to the blue side. When the focusing geometry varying from f/8 to f/3 (Fig. 1(d)–(a)), although the interaction length l is decreasing monotonously by increasing the focusing geometry, but the onset of the SC spectra is almost around 450 nm. This indicate that the temporal differential of electron density $N_e(t)$ play a more important role in extending the SC spectra to the blue side than the interaction length l.