Coherence Measurement of White Light Emission from Femtosecond Laser Propagation in Air

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Coherence Measurement of White Light Emission from Femtosecond Laser Propagation in Air

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Strong white light emission is observed from femtosecond laser propagation in air. The divergence angle of the white light emission is measured to be about 5 mrad. Young’s double-slits and a Michelson interferometer are used to investigate the coherence. The wavelength components of the white light emission are identified to have a good spatial coherence and a coherence time of about 0.5 ps.

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In recent years, femtosecond (fs) laser pulses were found to be able to propagate in air for up to 200 m as self-guided filaments.1 A supercontinuum (SC) white light emission from these filaments was obtained in a broadband wavelength range from the near-infrared to the ultraviolet.2–10

Generation of the SC is a universal phenomenon in laser transporting in most optical media and was first observed in 1970.11 In recent years, many works have been carried out to explain the physical mechanism of the SC. Self-phase modulation (SPM) is considered to be the most possible candidate for the generation of SC.2,4,7,8,11

The SC white light generated from the multi-filaments during the interaction of ultrafast intense laser with a wide variety of solids and liquids was identified to be spatially coherent.10,15–19 Temporal coherence length of the wavelength range between 800 nm and 500 nm was measured to be equal to the corresponding coherence length of 800 nm Ti:sapphire laser pulses in liquids.4 This SC light also has a small divergence as good as that of the input laser pulse.18,20,21 Such a white light is also called an ultrafast white laser.4,22

We present our measurements of the characteristics of the propagation of filaments in air.11–13 Young’s double-slits and a Michelson interferometer are used to investigate the spatial and temporal coherence of the strong white light emission. The divergence angle of the white light is measured.

The experiment was conducted using our homemade X1-Ii Ti:sapphire laser system operating at 800 nm with a repetition of 10 Hz. The laser system provided 640 mJ in 30 fs pulses. In our experiment, the energy per pulse was limited around 80 mJ.

Figure 1 shows the experimental setup to investigate spatial and temporal coherence of the SC light emission. The laser beam was focused into atmosphere by an f/160 mirror. The number of filaments was controlled by the focal length and the input laser energy. The inset shows a far field image after the SC occurred. A strong white core with colorful rings was observed.

![Figure 1. The experimental setup.](image)

A spectrometer was used to investigate the SC emission. The spectrum of the SC emission is shown in Fig. 2. A wide spectral range from 400 nm to 1100 nm was obtained from the SC emission. The cut-off of the long wavelength side was due to the limitation of our spectrometer.

The divergence angle of the white light generated with an f/160 focusing mirror was measured to be about 5.66 × 10⁻³ rad. As we changed the focusing mirror into f/300, the divergence angle was

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shown in the upper part of Fig. 4. The slit separation was 1 mm. A theoretical simulation is obtained by calculating the Fraunhofer double-slit interference pattern with

$$I_\theta = a_0^2 \left( \frac{\sin \alpha}{\alpha} \right)^2 \left( \frac{\sin(2 \beta)}{\sin \beta} \right)^2,$$

$$\alpha = \frac{\pi a}{\lambda} \sin \theta, \quad \beta = \frac{\pi d}{\lambda} \sin \theta,$$

where $a$ is the width of the slits, $d$ is the distance between the slits, and $\lambda$ is the wavelength. We integrate each component of the 400–900 nm lights and achieve a multicolour pattern. This agrees with the experimental result. We can then conclude that each component of the white light emission is partially spatially coherent.

5.39 x 10^{-3} \text{ rad}. Since the white light is originally generated from filaments, instead of the laser beam, the white light does not show any relationship with the change of the $F$-number of the focusing.

![Fig. 2. Spectrum of the white light.](image1)

![Fig. 3. The divergence angle of the white light. The solid squares are the experimental results with an f/160 focusing and the solid circles are the results with an f/300 focusing. The solid and dashed lines are the linear fits. The divergence angles are measured to be 5.66 x 10^{-3} \text{ rad} and 5.39 x 10^{-3} \text{ rad}, respectively.](image2)

![Fig. 4. A typical interference pattern of the white light. The upper pattern is the experimental result and the lower part is the theoretical simulation.](image3)

The spatial coherence measurements were made using a Young’s double-slit interferometer. The slit dimension was 2 cm long and 100 \mu m wide. The spacing between two slits was varied to measure the spatial coherence.

A typical experimental interference pattern is

![Fig. 5. (a) Experimental result of the interferential intensity distribution from a double-slit separated by 10 mm. (b) Theoretical simulation under the same condition.](image4)

To obtain the homochromatic interference pattern, a filter at 500 nm central wavelength (full-width at half-maximum: 100 nm) was applied. In order to examine the spatial coherence, we used a double-slit with 0.4 mm wide, separated by 10 mm while the diameter of the white light was 12 mm. The interference pattern is shown in Fig. 5. A simulation of an ideal Fraunhofer double-slit interference pattern under the same condition is shown in the following. About 50 patterns can be observed. The contrast of these patterns was not so good due to the poor quality of the double-slits we made. This measurement indicates that different spatial parts of the white light are phase related.

For the temporal coherence measurement, a Michelson interferometer was used. A grating was
placed to separate different wavelengths of the white light. Figure 6 shows the change of pattern visibility versus temporal separation with a central wavelength of 525 nm (full-width at half-maximum: 5 nm). The inset shows a typical pattern with a visibility of 0.7. A Gaussian fit of the experimental data shows a coherence time (FWHM) of 0.4 ps. The visibility is calculated by

$$V(t) = \frac{I_M - I_m}{I_M + I_m}. \quad (3)$$

![Image](image1.png)

**Fig. 6.** Change of pattern visibility versus temporal separation with a central wavelength of 525 nm.

![Image](image2.png)

**Fig. 7.** Coherence time of different wavelength components of white light.

We randomly select another 5 wavelengths across the white light, each having a constant width of 5 nm. A very similar coherence time of about 0.5 ps was obtained for each wavelength as shown in Fig. 7. Since the generation of SC is mainly due to self-phase modulation of the Ti:sapphire laser, it is easy to understand that each wavelength component of the white light has a similar characteristic of coherence.

The supercontinuum white light is considered to be generated from the self-phase modulation in intense laser propagating in the air. Different wavelength components are phase related. Each wavelength shows good spatial coherence and the coherence time is almost the same. The coherent time was measured to be about 0.5 ps. It has a small divergence angle of about 5 mrad and a propagating length of several hundred metres.

References


