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Talbot effect under illumination of double femtosecond laser pulses

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Abstract

The Talbot effect under illumination of double femtosecond laser pulses has been reported. Spectrums of double femtosecond laser pulses with phase differences are quite different from that of one single femtosecond laser pulse. Therefore, the Talbot images of the double femtosecond laser pulses with phase differences are different from that of one single femtosecond laser pulse. Specifically, for the phase difference corresponding to π, the Talbot image shows the largest difference from that of one single pulse. Experimental results are in good agreement with the theoretical analysis. The behaviors of Talbot images under double femtosecond laser pulses illumination cannot be obtained under one femtosecond laser pulse, monochromatic or polychromatic light illumination. Therefore, it is a new interesting optical phenomenon for the Talbot effect which should have potential applications.

Keywords: Femtosecond laser pulse; Spectral interference; Talbot effect

1. Introduction

Periodic structures will yield exact images of themselves at certain distances by free-space propagation of a diffracted field when illuminated by monochromatic light. This phenomenon is well known as the Talbot effect and it has received extensive investigations because of its wide applications [1–3]. The Talbot effect has been generalized to the domain of pulsed wave field [4], polychromatic wave field [5,6] and has also been discussed in the temporal domain [7,8]. With the rapid development of the femtosecond pulsed laser technologies, researchers have also studied the Talbot effect under femtosecond laser pulses illumination [9,10]. Recently, in experiments for measuring double femtosecond laser pulses, we found that the spectrums of the double femtosecond laser pulses with phase differences show large difference from that of one single femtosecond laser pulse. Thus it becomes interesting to investigate how the difference of the Talbot effect will change when it is illuminated by the double femtosecond laser pulses. In this paper, the Talbot effect under double femtosecond laser pulses illumination is studied. To the best of our knowledge, it is the first time that the Talbot effect is investigated concerning its behaviors under double femtosecond laser pulses illumination. We believed that the Talbot effect under double femtosecond laser pulses illumination should be a new optical phenomenon about the Talbot effect.

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2. The spectral interference of double femtosecond laser pulses

We assume that the femtosecond laser pulse has a typical Gaussian shape. The electric field of one femtosecond laser pulse centered at ω_0 in the time domain is given as

$$E(t) = \exp\left(-i\omega_0 t - \frac{t^2}{T^2}\right), \tag{1}$$

where the parameter T is related to the full width at half maximum (T_{FWHM}) of the $E(t)$ by

$$T = \frac{T_{FWHM}}{2\sqrt{\ln 2}}. \tag{2}$$

The pulse can be expressed in the frequency domain with the Fourier transform (FT) of $E(t)$ as

$$E(\omega) = FT[E(t)] = \frac{1}{2\pi}\int_{-\infty}^{+\infty} E(t)\exp(i\omega t)\,dt = \frac{T}{2\sqrt{\pi}}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{4}\right]. \tag{3}$$

Another femtosecond laser pulse has a time delay of τ, which can be written as $E(t-\tau)$. The FT of $E(t-\tau)$ can be written as

$$FT[E(t-\tau)] = \frac{1}{2\pi}\int_{-\infty}^{+\infty} E(t-\tau)\exp(i\omega t)\,dt = \frac{T}{2\sqrt{\pi}}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{4}\right]\exp(-i\omega\tau) = FT[E(t)]\exp(-i\omega\tau). \tag{4}$$

When double femtosecond laser pulses with a time delay of τ are spatially overlapped, it can be written in the time domain as

$$E_{double}(t) = E(t) + E(t-\tau), \tag{5}$$

so the double femtosecond laser pulses has the spectrum as

$$E_{double}(\omega) = FT[E(t) + E(t-\tau)] = E(\omega) + E(\omega)\exp(-i\omega\tau) = \frac{T}{2\sqrt{\pi}}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{4}\right][1+\exp(-i\omega\tau)]. \tag{6}$$

Spatial overlapping double femtosecond laser pulses with a time delay of τ shows the spectral interference. Double femtosecond laser pulses can be performed in experiments by using a Michelson interferometer, and its spectrum can be obtained by a spectrometer, as shown in Fig. 1. One femtosecond laser pulse is split into two pulses in half by a beam splitter (BS). Each pulse is reflected by mirrors, and the two pulses are then reunited with a time delay of τ between them. The two femtosecond laser pulses interfere with each other in a spectrometer, yielding the spectral interference fringes. The measured spectral intensity is [11,12]

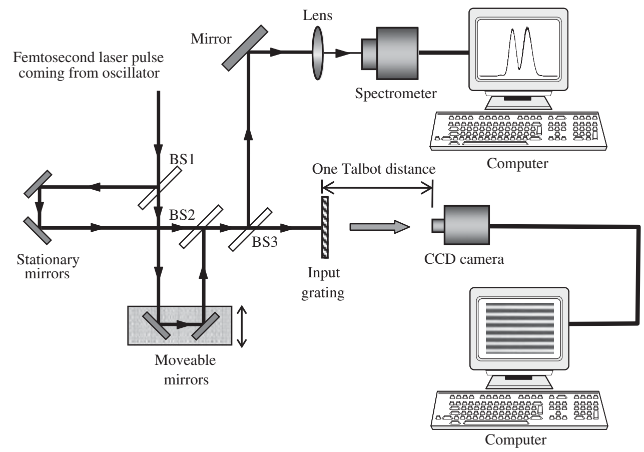

Fig. 1. Experimental setup for obtaining the Talbot images under double femtosecond laser pulses illumination.

$$S(\omega) = \left|E_{double}(\omega)\right|^2, \tag{7}$$

so the spectrum can be written as

$$S(\omega) = \left|\frac{T}{2\sqrt{\pi}}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{4}\right][1+\exp(-i\omega\tau)]\right|^2 = \frac{T^2}{2\pi}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{2}\right] + \frac{T^2}{2\pi}\exp\left[-\frac{T^2(\omega-\omega_0)^2}{2}\right]\cos\varphi, \tag{8}$$

where the first part is $2|E(\omega)|^2$, representing the sum of the spectrum of the pulses, and the second part is an interference term of them. The phase difference is $\varphi = \omega\tau = 2\pi c\tau/\lambda$, where λ is the wavelength of the broad spectrum of the femtosecond laser pulse and c is the velocity of light in vacuum. The phase differences between the two pulses vary as a function of the wavelength, leading to intensity maxima and minima in the interference spectrum. One observes a periodic intensity distribution with a period inversely proportional to the time delay. Each maximum and minimum in the interference spectrum corresponds to even- and odd-numbered multiples of π in the phase differences between the two femtosecond laser pulses, respectively. Assuming that the spectral intensity distribution of the femtosecond laser pulse has a Gaussian shape with a central wavelength of 810 nm and a spectral width (FWHM) of 35.99 nm (our femtolaser can be operated in this mode), with numerical simulation, the distribution of spectrums of double femtosecond laser pulses with different phase differences ($\varphi = 0, \pi, 400\pi$) are obtained, which are shown in Fig. 2. From the numerical simulation, we can find that for the phase differences of $\varphi = (2n+1)\pi$ (n is a integer), the central wavelength has a zero spectral intensity; for the phase differences of $\varphi = 2n\pi$,