Microoptical research in Shanghai Institute of Optics and Fine Mechanics

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This paper summarized the recent research results of Changhe Zhou's group of Information Optics Lab in Shanghai Institute of Optics and Fine Mechanics (SIOM). The first is about the Talbot self-imaging research. We have found the symmetry rule, the regular-rearranged neighboring phase difference rule and the prime-number decamping rule, which is briefly summarized in a recent educational publication of Optics & Photonics News, pp.46–50, November 2004. The second is about four novel microoptical gratings designed and fabricated in SIOM. The third is about the design and fabrication of novel supperresolution phase plates for beam shaping and possible use in optical storage. The fourth is to develop novel femtosecond laser information processing techniques by incorporating microoptical elements, for example, use of a pair of reflective Dammann gratings for splitting the femtosecond laser pulses. The most attractive feature of this approach is that the conventional beam splitter is avoided. The conventional beam splitter would introduce the unequal dispersion due to the broadband spectrum of ultrashort laser pulses, which will affect the splitting result. We implemented the Dammann splitting apparatus by using two-layered reflective Dammann gratings, which generates the almost same array without angular dispersion. We believe that our device is highly interesting for splitting femtosecond laser pulses.

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Microoptics techniques has taken great progress in recent years. The microlithographic technique is able to produce the fine microoptical element with the feature size of smaller than 1 μm. Therefore, novel microoptical element can be made to achieve new optical diffraction functions, e.g., using the microoptical elements in femtosecond laser area should be interesting for developing the novel femtosecond laser processing techniques.

In this paper, I summarized the recent results of Changhe Zhou's group of Information Optics Lab in Shanghai Institute of Optics and Fine Mechanics (SIOM). The first is about the Talbot self-imaging research. We have found the symmetry rule[1], the regular-rearranged neighboring phase difference rule[2], and the prime-number decamping rule[3,4]. The second is four novel microoptical gratings[5−8] designed and fabricated by us. The third is about the design and fabrication of novel supperresolution phase plates for beam shaping[9−12]. The fourth is the development of novel femtosecond laser information processing techniques by using microoptical elements, for example, use of a pair of reflective Dammann gratings for splitting the femtosecond laser pulses. We implemented the Dammann splitting apparatus by using two-layered reflective Dammann gratings, which generates the laser array without angular dispersion. We believe that our approach is highly interesting as a novel device for splitting femtosecond laser pulses.

Talbot effect is the self-imaging effect of a grating when it is illuminated by a monochromatic plane wave. The Talbot self-imaging effect is observed at the so-called Talbot distance as $z{=}nZ_T$, where $Z_T{=}2d^2/\lambda$, λ is the wavelength of the incident light, d is the period of the grating, and n is a positive integer.

New results on this subject have been obtained in the past few years. Symmetry of the Talbot effect is realized as the first step in revealing other rules[1]. Based on symmetry of the Talbot effect, number theory of the Talbot effect is found, including the regularly rearranged-neighbouring-phase-difference (RRNPD) rule [2] and the prime-number decomposing rule[3]. These works are summarized[4] on the Talbot effect.

We have designed and fabricated four novel gratings, including hexagonal grating based on the fractional Talbot effect for array illumination[5], double-layered computer generated hologram (CGH)[6], circular Dammann grating (CDG)[7], and symmetric color separation grating (CSG)[8].

A hexagonal array[5] not only is a nature-preferred pattern but also is widely used in optoelectronic materials and devices. We propose hexagonal grating for Talbot array illumination based on a binary phase grating.

The conventional CGH is single-layered, because the diffraction coupling between two-layered CGHs is difficult to establish. Recently, a two-layered CGH was described and implemented[6], in which the first layer is the encoding layer, and the second layer is the decoding layer. In the encoding layer, there are space-multiplexed multi-CGHs; in the decoding layer, there is a Talbot illuminator. The diffraction between two layered CGHs is connected based on the fractional Talbot effect.

Shifting the decoding layer or changing the patterns with spatial light modulator in the Talbot illuminator can display the different CGHs in the first layer one by one. This device should be applied to secure optical storage, micro-optical-electronic system, dynamic optical switching, etc..

Uniform optical field is always needed for laser processing of materials, laser fusion facility, laser writing, etc.. Borrowing the concept of superresolution effect, we put forward the CDG for uniform illumination of a circular array. CDG is a binary-phase circular grating that can be fabricated with a lithographic technique. CDG is demonstrated experimentally that it can be applied to practical applications, such as laser imaging system, laser processing of material, and uniform laser shaping, circular laser coupling, etc..

CSG can separate the different color components in one common optical path, e.g., blue, green, and red, simultaneously into different orders for filtering in laser fusion

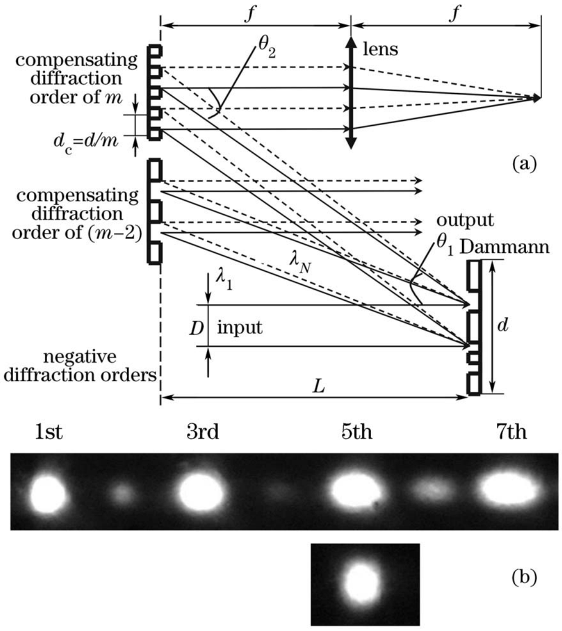

Fig. 1. (a) Splitting and compensating femtosecond pulses by a Dammann grating and the corresponding compensation gratings. (b) The above is the split positive part from a 1×8 Dammann grating (d=100 μm) without compensating. Note that the diffraction spots are becoming more elliptical due to the angular dispersion increase as the larger diffraction order, the below is the 5th diffraction order that has been compensated by a grating with period d_c=20 μm.

facility. The previous CSG is difficult to make because the vertical surface-relief profile is required for different phase levels. Symmetric color separation grating avoids this problem by using a symmetric structure of its surface relief profile, so it will be more easily fabricated and its cost will be low.

Small focal point is crucial for next generation of optical discs. We know that, the short-wavelength laser of 405 nm is not mature for commercial use, and the high-aperture lens of 0.85 is still difficult to make for mass production at a low cost. We report the use of the super-resolution technology to decrease the size of the so-called Airy diffractive spot. The phase plates for supreresolution effect are designed and fabricated with the microoptic technique. When such a phase plate is inserted into the optical system, the central spot at the focal plane of a lens is decreased to be 0.8 times of the Airy pattern, implying the possibility of reading higher storage density with a normal lens of NA = 0.6. The most attractive feature is that the phase plate can be mass-produced at a very low cost. We have also demonstrated the use of superresolution techniques for laser beam shaping and other applications[9−12].

Splitting a beam plays an important role in measuring an ultrashort laser pulse by an autocorrelator or any other methods. Semireflecting mirror is generally used as the beam splitter that invariably introduces the material dispersion. One of the pulses is not equal to the other and the beam splitter was even 2-μm-thick in some stringent experiments.

Using the Damman grating to split a beam of femtosecond laser pulses into the multiple equal intensity beams, chromatic dispersion will occur in each order of diffraction beams with different scale of angular dispersion that is caused as the incident ultrashort pulse contains a broad of spectral bandwidths. We proposed a novel method[13] that the angular dispersion could be compensated by positioning an m-time density's grating to collimate the mth order beam that has been split. Therefore, array of beams that are free of angular dispersion are obtained with this method. It should be highly interesting in practical applications of splitting femtosecond laser pulses for pulse-width measurement, pump-probe measurement, and micromachining at multiple points.

This paper summarized the recent four microoptical research results of Zhou's group of Information Optics Lab in SIOM. The first is about the Talbot self-imaging research. We have found the symmetry rule, the regular-rearranged neighboring phase difference rule and the prime-number decomposing rule. The second is about four novel microoptical gratings designed and fabricated in SIOM. The third is about the design and fabrication of novel supperresolution phase plates for beam shaping. The fourth is to develop novel femtosecond laser information processing techniques by using microptical elements, for example, use of a pair of reflective Dammann gratings for splitting the femtosecond laser pulses. The most attractive feature of this approach is that the conventional beam splitter is avoided. The conventional beam splitter would introduce the unequal dispersion due to the broadband spectrum of ultrashort laser pulses, which will affect the measurement result. We implemented the Dammann splitting apparatus by using two-layered reflective Dammann gratings, which generates the almost same result as the FROG method. We believe that our approach is highly interesting as a novel device for measuring femtosecond laser pulses.

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