NOVEL DESIGNS AND APPLICATIONS
OF SPECIAL DIFFRACTION
GRATINGS IN OPTICAL SYSTEMS

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Novel Designs and Applications of Special Diffraction Gratings in Optical Systems

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Abstract

The diffraction phenomenon was demonstrated for the first time by Leonardo da Vinci at 15th century. After that, many scientists have done lots of research and proposed a series of theories and demonstrations. In general, diffraction comes from the limitation of the lateral extent of a wave. Diffraction arises when a wave of a certain wavelength collides with obstacles. The smaller the obstacles, the larger the diffraction effects become. A grating can diffract light in a given direction, just as a prism would, but it can actually take any physical configuration and form. In this thesis, we introduce several diffraction gratings with different purposes. In general, they are mostly in circular shape. A circular grating is defined, in this thesis, as a number of concentric circular rings of constant radial spacing on a plane surface. The rings can be alternately controlled by amplitude grating which has alternating absorbing power or phase grating where the refractive index varies in an alternating manner. Circular Diffraction Gratings can be used in many areas, and in this thesis, we aim to explore the potential applications of Circular Diffraction Grating by employing novel designs, specifically in the areas of optical measurements and optical storage system.

Firstly, we introduce a special diffraction grating, namely, Circular Diffraction Grating (CDG). Zhou, Zhao, Chung and Wen et al proposed the concept of CDG
employing different methods in generating ring patterns. We have explored the feasibility study of employing CDG in measuring the area of an object and the distance between objects using Wen’s method. The experimental results show that they agree well with the theoretical calculation. Through the Charged Coupled Device (CCD) camera, the diameter of the major axis in CDG can be measured. The accuracy is governed by the focal length of the converging lens and the period of the grating. Due to a limited aperture of the grating and diffraction efficiency (around 60%) of the grating, an error rate of less than 5% can be achieved.

In order to achieve better the performance and efficiency, we propose to transfer the structure into a high density design which is defined as the ratio of period/wavelength to within a single digit. We have experimentally and successfully proved this method by designing odd-port beam splitters. Then we continue to design high density Circular Diffraction Grating. To get a mathematical expression of the Circular Diffraction Grating, we have to borrow Maxwell’s equations. The electric and magnetic field are linearly polarized and the continuum of solutions resulting from Helmholtz’s equations is sufficient to give a complete description of the propagation of this optical wave. We have also employed a numerical simulation method, the finite-different-time-domain (FDTD) to prove the results. We also discuss the fabrication steps and challenges for high density grating. Many different
fabrication methods exist for various diffraction gratings. Most of these techniques can be grouped into two main categories: lithographic techniques and electron beam writing. The selected fabrication method and working principles within their limitations are important factors in obtaining desired grating efficiency. As described, maintaining the designed grating depth is critical to guarantee high transmission efficiency. Missing one or more depths may result in zero-order transmission. We have analyzed these fabrication methods with different parameters.

Furthermore, we introduce another form of circular diffraction gratings, called Circular Bragg grating. This grating is employed in holography and has been extensively studied in various areas. With the advantages of parallel data processing and high speed access, applications of holographic technology in data recording system have been expanded significantly in recent years. To start with, we have designed single beam multiplexing in dual modulation spatial light modulator (SLM) and pure phase modulation. In order to increase the data storage capacity, Circular Bragg diffraction condition is proposed. We utilize a SLM to phase modulate the reference beam with blazed-grating pattern and amplitude modulate the signal beam. Data can then be stored two-dimensionally in the same area of a photographic plate and hence the data storage density can be increased.

To conclude, we have demonstrated our novel design of applying special
diffraction grating to optical measurement and optical storage. Both theoretical and experimental results agree well with each other. We believe that this grating can have potential applications in many areas.


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