Editorial

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Diffractive optics

https://doi.org/10.1515/aot-2021-0007

Dear reader,

It is a pleasure for me to be invited as a guest editor for an Advanced Optical Technologies edition on diffractive optics.

My journey with diffractive optics began in November 1986 when I attended my first lecture on optics by Adolf W. Lohmann at the University of Erlangen in Germany. Recently, I found my notes from this lecture. Adolf W. Lohmann, who coinvented the computer-generated holograms (CGH) in the 1960s, made very clear statements in this lecture: “The electronic computer is at the end. There are fundamental limits in Physics which do not allow to make electronic computers much faster than they are today. We will reach these limits in several years. The only chance is to develop optical computers now. Diffractive optics is the key to success.”

He then explained his vision of diffractive or planar optics. “Planar optics has the potential to replace a bulky and heavy telephoto lens with a thin light-weight element.” I was impressed and started my diploma work on dichromated gelatin (DCG) holograms some months later at his institute.

As often in history, not all predictions about the future have been realized. And technology development always takes much longer than expected. My 500-mm telephoto lens is still heavy, but recently I bought the new version with integrated phase Fresnel (PF) optics, bringing down the weight from 3 to 1.5 kg. It took industry a bit longer than Adolf W. Lohmann had predicted, but as a photographer, diffractive optics—or planar optics—makes my life better. But how does it work? Is a “phase Fresnel” element really diffractive optics?

This is where the problems with diffractive optics start. It is not so trivial to understand the physics behind and it is not so trivial to integrate diffractive optics into a real device. A Fresnel lens, as invented 1822 by Augustin Jean Fresnel for light houses, is certainly not diffractive optics. But it was a great idea to reduce weight and costs of bulky collimation optics in light houses. To decide whether a Fresnel lens is refractive or diffractive, we need to know the width of the Fresnel rings or zones. My telephoto lens is certainly diffractive optics, because the complementary dispersion allows the correction of chromatic aberrations in a very elegant way.

Integrating diffractive elements into photographic lenses started some 25 years ago. The first lenses still suffered from straylight and ghost images under certain illumination conditions. A diffractive optical element diffracts the incoming light in many diffraction orders. There will always be some light in the unwanted orders. These problems are solved for my new telephoto lens. My new lens is perfect, and industry is getting closer to Adolf W. Lohmann’s dream.

And what happened to computers? Electronic computers are still getting more powerful every year. No need for an optical computer. However, diffractive optics has become a decisive key enabling technology for lithography, the backbone of microchip manufacturing. A modern lithography tool is full of diffractive optical elements for laser bandwidth-narrowing, beam shaping, focus and overlay control, and metrology. The phase shift photomasks (AAPSM) used for lithography in semiconductor manufacturing are nothing else but computer-generated holograms (CGHs). Adolf W. Lohmann’s invention was decisive to shrinking the minimum feature sizes of a transistor or memory cell to a few nanometers. Johannes Wangler, the late “illumination guru” at Carl Zeiss SMT, once told me that half of the way from 1-μm resolution to some nanometer today was achieved by integrating diffractive optics in the lithography tools.

The basic idea behind the optical computer was to eliminate the so-called electronic bottleneck by building an all-optical computing and networking system. This did not work out for computing yet, but the all-optical network is the backbone of our telecom and data networks already. Adolf W. Lohmann’s was right—although things evolved differently than he predicted. Still, we have not understood all aspects of diffractive optics and still we discover very promising new fields of applications for diffractive optics.

One of the new fields for diffractive optics is automotive lighting. AOT already dedicated a special issue on automotive lighting with guest editor Cornelius Neumann in November 2020. One article of the current issue presents a

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new approach for a laser-based rear end lighting system with diffractive optics. This article fits well to the “micro-optics revolution in automotive lighting” predicted by Jose Pozo from EPIC in May 2020. Planar optical elements could help to reduce the size and weight of bulky front- or rear lights in a car and open new applications like light carpets and miniaturized projectors for interior and exterior lighting.

One article deals with a novel method for an inverse design of diffractive optics by using a step-transition perturbation approach (STPA). The proposed method allows to create wide angle diffractive optics which is very popular for applications like face recognition today.

Imprint technologies allow manufacturing diffractive optics on wafer-level using tools from semiconductor manufacturing like mask aligners. One article of this issue describes the recent trends for manufacturing of diffractive optics by nano- and microlens imprint technologies.

For imprinting of diffractive optics, the choice of materials is still very limited today. Critical issues for these materials are process parameters like curing time and viscosity, lifetime, especially the resistance to UV light or heat and optical properties like refractive index and Abbe number. One article deals with recent improvements of optical materials for wafer-scale manufacturing of diffractive optics.

A high refractive index and excellent hardness and resistance against high laser light is provided by diamond-based diffractive optics. One article discusses state-of-the-art and recent progress in this interesting field.

Waveguide gratings and conformal dielectric-plasmonic coatings providing narrowband transmission filtering are presented in one article. One article deals with the stray light characteristics and its optimization for geometrical waveguide optics.