Thin Switchable Liquid Crystal Fresnel Lenses

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ABSTRACT

A summary discussion of the manufacturability and implementation issues concerning switchable liquid crystal based Fresnel lenses fabricated on thin, semi-flexible foils is presented.

1 Introduction

Switchable lenses of a foil-like, ultra-thin appearance and associated limited diameters have a great potential for applications such as smartphones, medical instruments, wearables like contact lenses and even intra-ocular lenses. Liquid crystals as the switchable medium has been considered the obvious choice for quite some time [1-3].

Of the numerous types of liquid crystal lenses the ones considered here are based on the conventional segmented Fresnel design.

The basic working principle of such a lens is shown in figure 1. Starting from planar LC alignment, in the unpowered state the mismatch between the ordinary refractive index of the LC and the index of the lens shape material will give the intended focusing power. Once an electric field is applied, the liquid crystal molecules will reorient themselves to the vertical position. If the materials are suitable chosen, i.e. if the extraordinary index of the liquid crystal equals the index of the lens material, then the mismatch of the refractive indies will reduce until in the vertical position refraction no longer occurs. So one can switch between a designed optical power and no optical action. Switching between two given optical powers is of course also possible by adding a curvature to the outer side of the stack, in which case the driven (vertically aligned) state would correspond to the optical power of that curved surface.

The functionality of the cell is inherently polarization-dependent as can be readily seen from figure 1. Consequently, a polarizer must be present in the lens stack to ensure correct behavior. The reduction of the transmitted light by 50% can of course be a limiting factor to the usability. A possible solution to obtain polarization independent light transmission is to stack two lens cells rotated over 90º on top of each other, as illustrated in figure 2. Either polarization will then experience an equal refraction. This of course comes at the cost of increased complexity and total thickness and the possibility for parallax effects.

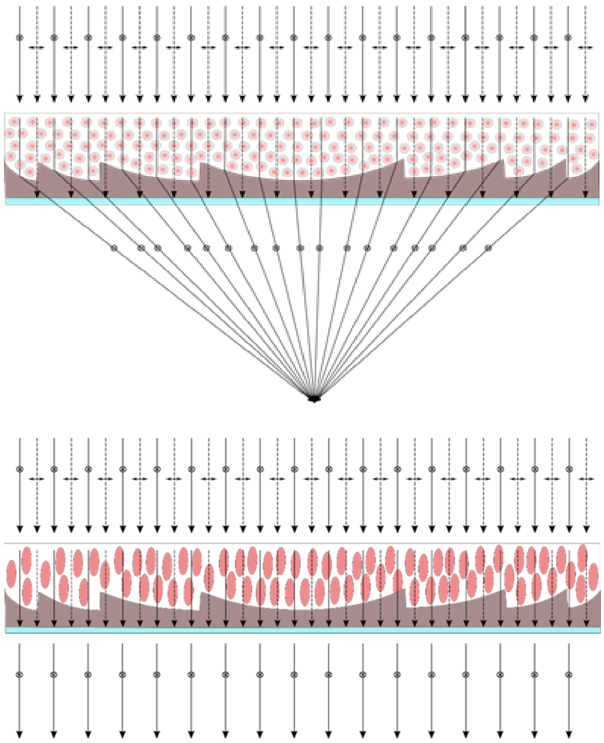

Fig. 1 Basic liquid crystal Fresnel lens working principle.

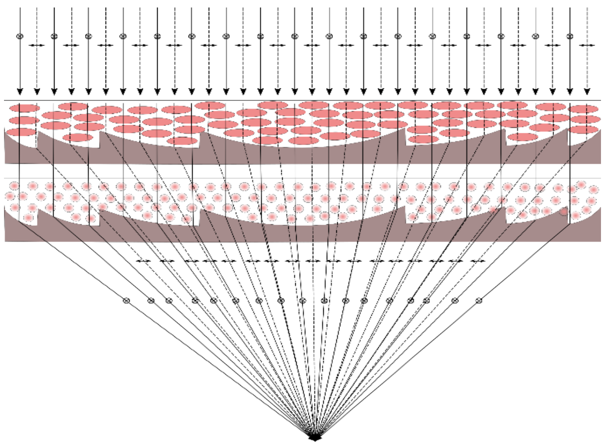

Fig. 2 Stacked version of the switchable liquid crystal lenses to obtain polarization independent functionality

2 Results

2.1 Manufacturing considerations

The application domains of the lenses are conducive to small lens diameters in combination with relatively long focal lengths. This results in slow lenses, with working f–numbers in the range of 10 or more.

On the other hand, a key feature of Fresnel lenses is their low profile height for a given power. Together this enables a lens where the segment height can be kept as low as a few micrometers while the lateral dimensions of each segment are in the range of a few hundred micrometers, resulting in only ten to twenty segments and very faint segment slopes [4]. Combined with the thin polymer layers that constitute the base substrates for the liquid crystal cell this guarantees that the total lens thickness can remain as limited as a few hundred micrometers.

Apart from a very thin lens, this also ensures a thin liquid crystal layer, a crucial parameter to maintain the switching speed as high as possible.

Fresnel lenses can be constructed in two ways: with constant pitch or a constant height. For minimum profile height and ease of manufacturing the constant height option is the preferred route. The most beneficial manufacturing technique has proven to be soft-lithography, where the structures are imprinted in a UV-curable material [5].

In the case of Fresnel lenses, the alignment layer for the liquid crystal needs special attention as it must be applied over the topography created by the lens segments. Uniform coating of conventional polymer alignment layers is not straightforward under such circumstances. Moreover, the rubbing technique itself is also hardly compatible with the circular symmetry of the Fresnel segments. Once again, although some artefacts remain inevitable, low profile heights at least alleviate this problem.

An even better solution is the use of inorganic alignment layers applied with the oblique evaporation technique. Since the application of the layer is in principle contactless, this eliminates any problems with coverage uniformity and offers a way of completely removing all artefacts [6].

2.2 Performance considerations

Tunable lenses are usually optimized for one specific optical power and are then switched between two nominal powers (one of which is then provided by the surrounding encapsulation and which can of course be zero). This has the advantage of simplicity in both optical design and electrical driving. The two states then correspond to the unpowered state and a fully switched liquid crystal, which means the driving voltage does not need to be an exact value and only must be chosen high enough. However, intermediate effective refractive indices for the liquid crystal layer can be obtained with proper electrical driving which should in turn yield intermediate focusing distances. In principle, since optimization of the single lens surface can only yield optimum results for one configuration, optimal performance at intermediate focal distances is not a priori guaranteed.

Nonetheless, the performance at intermediate levels does not seem to deteriorate to any appreciable level.

These performance levels are however assuming a perfect manufacturing process and disregard any inevitable tolerances that will be incurred. Specifically for the process, the use of thin foil materials makes the lens susceptible to mismatches between the intended local liquid crystal thickness and the real values.

An adequate gap spacing control is thus needed to achieve maximum performance. This involves both the control of the initial spacer configuration as well as the subsequent lamination process.

3 Conclusions

Tunable liquid crystal lenses based on the Fresnel design have been discussed, showing their adequacy and performance level when working at high f-numbers.

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