Diffractive Optical Elements for Passive Infrared Detectors

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Abstract: Complex diffractive lens arrays for passive infrared detection systems have been designed and fabricated by laser beam writing and injection moulding. Continuous relief profiles with depths up to 20 μm were originated, characterised and replicated.

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1. Introduction

Passive infrared detectors for motion detection and intrusion alarms use a complex, multi-element lens array to focus the target field onto an infrared detector and generate an alarm when an object moves across the field. The moving object produces a characteristic time-dependent signal as the images formed by the various lenslets in the array move across the detector.

The lens arrays are mass-produced by injection moulding in infrared (IR) transmissive polyethylene from a complex mould tool. Such moulds have been thus far been typically produced by micro-machining techniques. In this paper we describe the use of Diffractive Optical Elements (DOEs) for this application. Each DOE is an array of diffractive lenslets designed and optimised for a given detector type – Fig. 1 shows a typical array. The fabrication of the original DOE microstructure is done by direct laser writing in photoresist. This allows the fabrication of complex lenslet arrays in a single writing step and opens the door to increased functionality and new detector features. In the example shown here, the lenslet array is optimised for a home detector which can distinguish between persons and pets and generate an alarm only for the former.

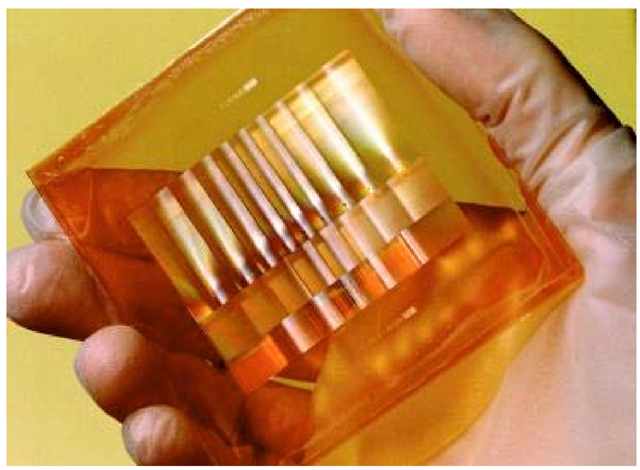

Fig. 1. Lenslet array recorded in photoresist for custom IR detector application.

2. Fabrication: Direct Laser Writing

The polymer lenslet arrays are fabricated using the following steps:
1) Design of lenslets and array
2) Origination by direct laser writing in photoresist
3) Electroforming of an injection moulding tool insert
4) Injection moulding in PE (Polyethylene) for mass-production

The lenslet array shown in Fig. 1 was fabricated using the CSEM LaserWriter system [1] shown schematically in Fig. 2. The individual lenslets were designed as anamorphic diffractive lenses, i.e. having different focal lengths f_x and f_y along the x and y axes.

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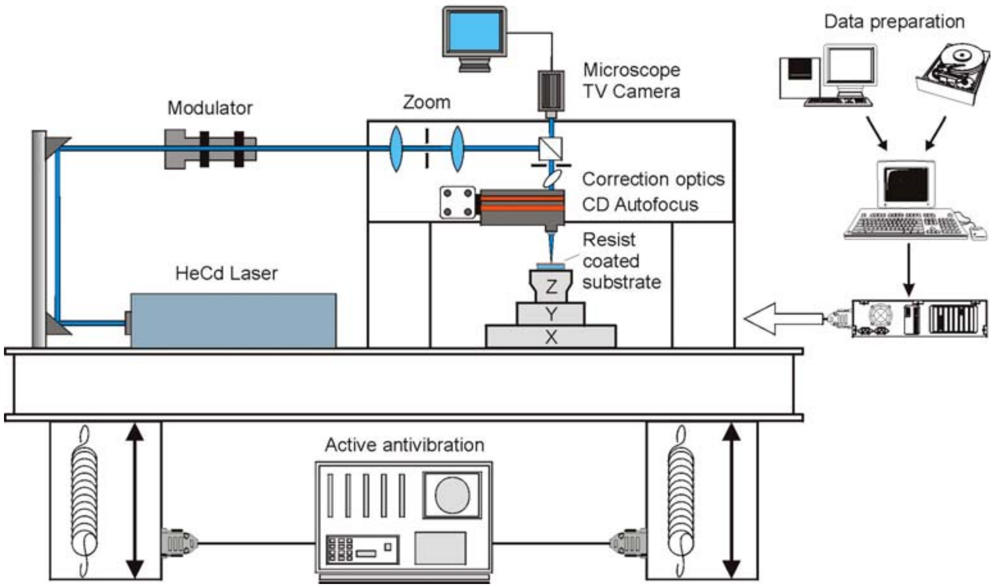

Fig. 2. CSEM`s LaserWriter system for fabricating DOEs by direct laser beam writing

The focal lengths f_x and f_y of each lenses in the array are optimized in order to achieve the required spatial distribution and the signature typical for a human intruder. The horizontal focal length f_x sets the observation range; the values of f_x vary from 10 - 25 mm over the whole array, which typically consists of 20 - 25 individual lenses. By setting f_y to a higher value (typically up to 80 mm) the optical signal of an IR source with a predominantly vertical shape can be increased (= human) compared to a source with a horizontal form (= pet).

Conventional lenses for IR sensor applications are fabricated by diamond machining and are combined to an array by replication techniques. The fabrication with microstructuring technologies such as direct laser beam writing offers several advantages over conventional Fresnel-type lenses:

- For sophisticated spatial detection patterns, different focal lengths can be combined in an array with no additional cost.
- Non-rotationally symmetric elements (including anamorphic lenses) can be fabricated.
- The DOE can be tuned for optimum performance at the wavelength range of interest, 7-14 µm, reducing the false alarm rate by about 15% in practice.
- Due to the reduction in sag when replacing a classical Fresnel element by a diffractive structure, the overall thickness of the element can be reduced, leading to lower absorption and higher signal levels. The mechanical strength of the 500 µm thick injection moulded piece is also significantly improved by the replacement of a classical Fresnel element with about 250 µm maximum depth with the DOE of only a few µm depth.
- Customer specific labelling of the array can be done in the same fabrication step.

The design wavelength was set to $\lambda_0 = 10.0$ µm, considering the typical IR emission spectrum of an object at a temperature of 25 - 30°C and the sensitivity of the pyroelectric detectors. Polyethylene (PE) is a material with good transmission characteristics in the mid IR and excellent suitability for injection molding. The index of refraction at λ_0 is $n \approx 1.51$, leading to a profile depth for a first order diffractive lens of $d \approx 20$ µm. The ability to fabricate deep microstructures by photolithography is thus the key for applying plastic diffractive optics in the infrared wavelength region. Since such continuous-relief profile depths are beyond the limits of standard lithography techniques, special emphasis has to be put on the optimization of film preparation and exposure parameters. The fabrication methods that are currently used at CSEM for diffractive and refractive micro-optical elements in the visible wavelength range were adapted and optimized [2].

Fig. 3. Ni mould insert electroformed from photoresist original.

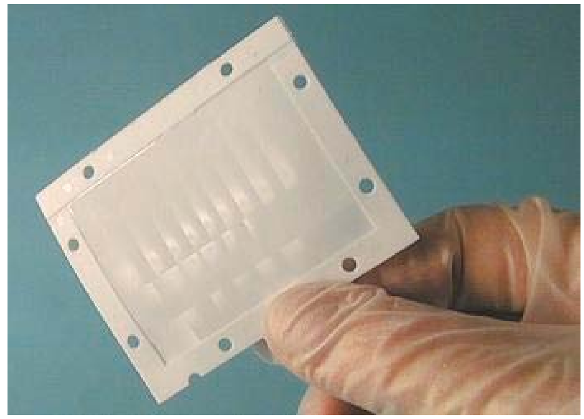

Fig. 4. Injection moulded lenslet arrays in polyethylene.

Films of Shipley S1828 photoresist were spun in a single step to a thickness of 20 μm on glass substrates and exposed in a slightly modified direct laser writing process. Various effects such as the bulk absorption of the photoresist and an increased isotropic component in the development process required additional characterisation runs on test structures. Blazed gratings with different periods and diffractive test lenses were originated by laser beam writing and measured in an IR characterisation set-up.

Following fabrication of the original in photoresist, it is electroformed to a Ni insert tool for the injection moulding [3]. The tool is electroformed to a thickness of 1 mm and polished on the rear side to produce a high quality insert for the moulding. Consistency of the insert tool flatness and thickness are of paramount importance, since the finished component is only 0.5 mm thick and any distortion in the tool will result in a deviation in section thickness of the final moulded component, causing an erratic performance.

The lenslet arrays are moulded in a special polyethylene material for use in the mid IR for these applications. As with all thin section injection moulding care has to be taken to ensure an even fill process to minimise any stress as that would have a detrimental effect on both optical performance and the geometric/mechanical stability of the component. Figs. 3 and 4 show the moulding tool insert and an injection moulded PE lenslet array. Fabricated elements have been tested extensively and show an excellent performance.

3. Conclusions

The use of DOE designs for the lenslet array in Passive Infrared Detectors adds flexibility and new functionality to the system performance. Such elements have been recorded in photoresist using the CSEM LaserWriter and electroformed to a Ni tool insert for injection moulding. Replicas were produced by injection moulding in polyethylene. The resulting DOE lenslet arrays have been successfully tested in Passive IR Detector units and shown to result in improved performance and new features.

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