Bringing order into light with structured polarisers

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Optical technologies are making increased use of the polarisation of light as an additional source of information. Not only does this result in more stringent optical parameters for polarisers, but so too for their physical structure. Structured polarisers comprise regions producing different orientations of polarisation and/or regions covering different spectral ranges, and represent a major challenge to the manufacturing industry. Dichroic polarisers, those that make use of the deformation of silver nano-particles, are proving to be the most likely route to the successful manufacture of finely structured polarisers.

The polarisation of electromagnetic radiation, and in particular that of visible light (wavelength 390 to 780 nm) has been utilised successfully in optics for many decades, for example for the suppression of reflected light in photography, for the analysis of optically active materials in polarimetry or for measurement of thin film thickness and their optical constants in ellipsometry. More recently, increasing attention has been given to the potential for polarisation to gain additional information, as diverse structures and materials affect the polarisation differently.

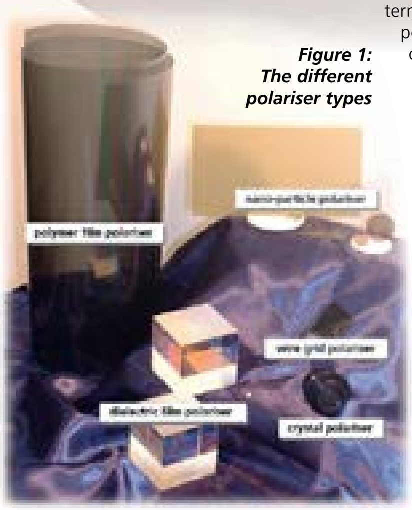

Figure 1: The different polariser types

Polarisers are currently available on the market in many varied forms and can be differentiated by the physical principle employed to generate the polarisation, by their specification in terms of contrast, transmission and relevant wavelength range, and notably also by price. The most widely spread type of polariser in use is the film polariser, which can be quantified alone through its use in LCD displays in terms of km^2. However, as this type of polariser is rather specific in terms of use, and despite being a very cost-effective solution in the visible spectral range, it falls short in many other performance related areas such as contrast ratio, homogeneity, transmission and wavelength coverage. For this reason, we see several other types of polariser (**figure 1**) available to the user, and these can be categorised into five major groups:

1. Film polarisers as based on uniformly oriented molecular dyes embedded within a supporting film.
2. Crystal polarisers make use of the optically active properties of specific, mostly optical uniaxial crystals such as calcite. The various different types, e.g. Glan-Thomson, Rochon or Wollaston, are used to achieve particular effects, such as polarisation dependent beam deviation, reflection or displacement.
3. Dielectric film polarisers, the two most popular designations being TCP (thin film polariser) and PCB (polarising cube beam splitter), utilise the polarisation dependent reflection observed at the interface between materials of differing refractive index for all angles away from normal incidence. The polariser is rotated in order to use the Brewster angle reflection – through the appropriate choice of mutually interfering thin films, then near ideal performance can be achieved for both transmission and reflection.
4. Wire grid polarisers reflect polarisations (or components thereof) lying parallel to the grid wires, whilst the perpendicular component is transmitted.
5. Nano-particle polarisers utilise the polarisation dependent plasmon absorption exhibited by elongated metal nanoparticles embedded within a transparent dielectric medium such as glass.

Each of the different polariser types have specific applications fields where that type is used exclusively.

Structured polarisers

In general, a polariser effects the whole of the optically beam equally, i.e. the exiting beam is uniformly polarised over its whole cross-section. However, an increas-

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Figure 2: Structured polarisers exhibit regionally varying polarisation (orientation, spectral region)

ing number of applications require that different regions within a beam are handled differently, for example for spatially resolved polarisation analysis or for complex, optically coded keys [1].

The corresponding demand for appropriate polarisers is therefore also on the increase. These polarisers produce variations of polarisation for neighbouring sub-sections within the cross-section of a single beam, producing either spatially or spectrally varying orientation of the polarisation (**figure 2**). Such patterned polarisers can also include fully transparent or opaque regions.

Depending on the particular application, these polarisers are subject to specific requirements regarding spectral range, contrast ratio and transmission, and additionally with regard to their geometrical form factor. At one extreme, the regional variation across the useable aperture of a polariser can be down in the range of µm^2, while at the other extreme this may be as large as several cm^2. These parameters in turn define which type of polarising principle can be most effectively employed (or not).

The examples shown in figure 1 illustrate that not all polariser types can be effectively structured. Thin film and crystal polarisers, primarily because of their form factor, find only very limited application, whereas planar polarisers are much more suitable, i.e. foils or glass films where polarisation effects take place in surface-near regions or in layer systems attached to a thin substrate.

There are three principal methods of manufacture – mosaic, lithographic and thermal modification – each being most appropriate for specific polariser dimensions or requirements. Alternative methods for achieving structure, such as through the use of lasers or electric fields, do show great potential but are currently not capable of producing the necessary consistency and will not be discussed further.

Mosaic methods

Mosaic methods are most suitable for more coarse structuring (>2 mm), where the desired structured is achieved by arrangement of suitable sized filter segments. Differing, regionally specific polarisation orientation is achieved by simple rotation of the appropriate segment (**figure 3**). Note that this type of construction can also incorporate entirely opaque or transparent segments, as well as segments covering different spectral ranges.

In the transition regions between segments, transmitted light is subject to disruption. To what degree this represents a problem depends on the application, and is primarily determined by the quality with which the individual segments are produced and whether the optical active component of the element has been disturbed. Through the use of nanoparticle polarisers, gap sizes ranging between 20 and 100 µm can be attained. The filter mosaic is embedded between a base and cover layer to provide stability. Subsequent grinding and polishing reduce wave front distortion and beam steering to optically acceptable levels.

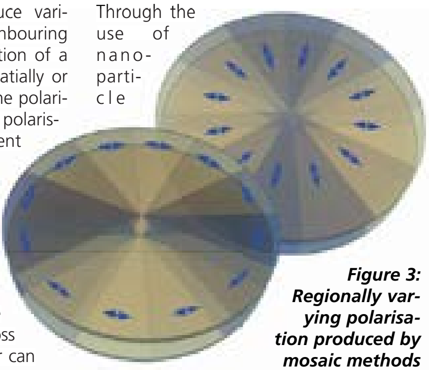

Figure 3: Regionally varying polarisation produced by mosaic methods

As the polarisation performance of the mosaic is dependent upon that of the chosen raw polarising material itself, then the pros and cons of that material must be weighed alongside cost issues when making

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the choice. On the one hand, glass can be precisely cut and trimmed to size and possesses a suitable refractive index and transmission over a broad wavelength range, even outside the visible range. On the other hand, while foil polarisers are more cost-effective, individual segments can not be so cleanly produced and assembled.

Lithographic methods

When the desired structuring is too small, or the segment arrangement too complex, then manufacture turns to lithographic methods. The prerequisite for use of lithographic methods is that the polarising layer is positioned on the surface or is at least surface-near so that suitable process methods such as etching can be used.

Glass polarisers incorporating elongated silver nano-particles are particularly well suited to this method of manufacture [2]. The polarising particles are produced by substitution of sodium ions in sodium silicate glass for silver ions, which through a subsequent reducing annealing process then form surface-near silver colloids of varying sizes. A further process step elongates the colloids in a preferential direction. The central wavelength of maximum polarisation, the degree of polarisation and the transmission are determined by particle size, particle density and the degree of ellipticity. Polarisers manufactured using this technology generally exhibit high contrast and good transmission, and are additionally environmentally stable (i.e. temperature, UV & chemically stable). With a thickness between 200–500 µm, they can be handled just like any other thin glass material.

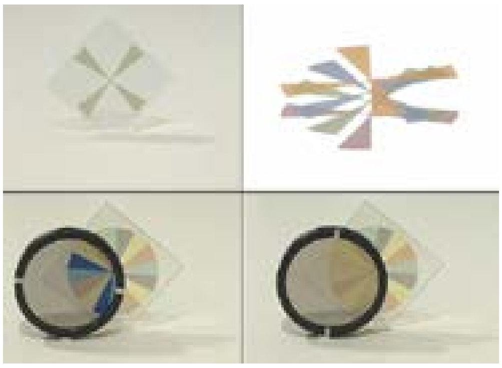

Figure5 : A multi-layered, lithographically structured polariser: several single layers (above left) are combined into a single structure (above right)

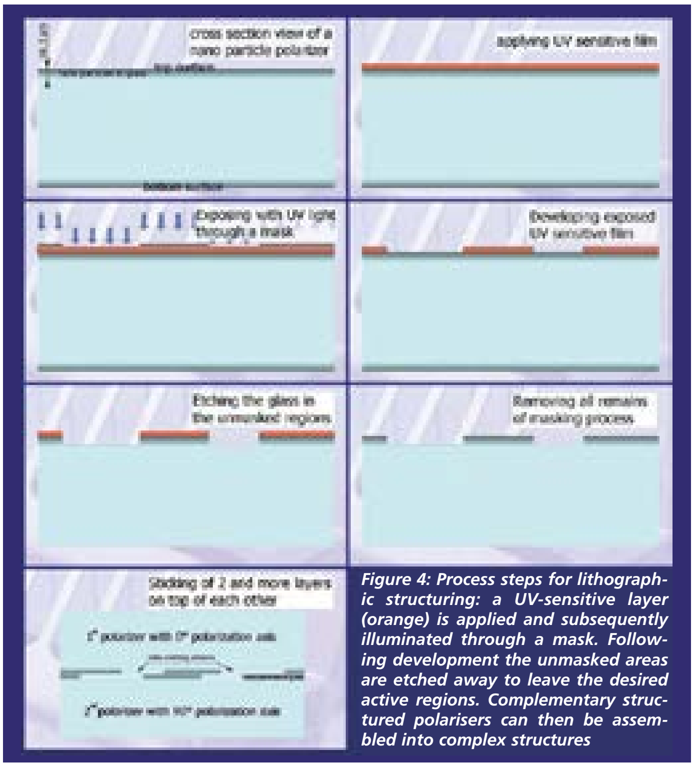

Figure 4: Process steps for lithographic structuring: a UV-sensitive layer (orange) is applied and subsequently illuminated through a mask. Following development the unmasked areas are etched away to leave the desired active regions. Complementary structured polarisers can then be assembled into complex structures

Using lithographic techniques, one or more glass polarisers can be prepared, each exhibiting different polarisation orientations and even incorporating entirely opaque or transparent regions. Through use of masking techniques typical of those found in the semiconductor industry, polarising regions that are to be retained in the final device are covered with photoresist, and subsequent etching of the layer containing the nano-particles produces regions that are transparent. The structures are designed such that stacking of the individual polarisers yields the desired final structure, noting that a polariser or an entire layer is required for each polarisation direction. A simple example is depicted in **figure 4**. Two polarisers are first given a checkerboard structure and then aligned so that the polarisation axes are orthogonal to one another and so that the transparent regions of one layer cover the polarising regions of the other. The result is a checkerboard arrangement of orthogonally polarising squares exhibiting minimum parallax (as the two polarising surfaces can be placed directly next to one another).

The lithographic method best lends itself to the manufacture of structured polarisers possessing two different directions of polarisation, where regions of complete transparency or opacity may also be included. Structure resolution is determined by available etch processes and the thickness of the polarising layer. Segment sizes down to roughly 5 µm are possible, but require cumbersome process steps such as ion beam etching. As the alignment of the separate layers is only limited by the bonding process, a high degree of accuracy is achieved – use of mask alignment systems reduces tolerances down to the sub-µm range.

The number of polarisation directions present in the structure can be increased by simple stacking of multiple layers (**fig-**

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ure 5). Structures comprising four such layers are typically 1 mm thick. Moreover, the use of raw polarising material optimised for different wavelength regions allows the manufacture of structures designed for use in specific wavelength regions – for example, the colorPol polarisers are available for the wavelength range 340 nm to 5 µm.

Thermal modification

For applications requiring varying spectral performance for a given polarisation orientation, it is possible to alter the particle deformation through application of a laser or electron beam process. Reduction of the ellipticity shifts the position of the absorption band toward the blue (e.g. to around 410 nm) and thus alters the spectral position of maximum polarisation. The key concept here is the shape relaxation of surface-near, uniformly oriented, polarising nano-particles embedded in a glass, and the method is thus restricted to appropriate glass polarisers.

Figure 6: Structured polarisers can be mass produced (using techniques similar to those used for wafer production)

Both the lithographic and the thermal methods provide a cost-effective route to filters comprising a limited number of small polarising segments. In a similar fashion to the semiconductor industry, large "glass wafers" containing a large number of filters can be manufactured, and these can be separated into individual components just as is the case for microchips in the electronics industry (**figure 6**). For the manufacture of this type of filter, each comprising an area of just a few mm^2, there is currently no economically and industrially feasible alternative.

Literature:

[1] Patent *Optisches Sicherheitssystem* DE 000 010 225 375 B4

[2] A. Volke, G. Heine, *Mit kleinen Partikeln ganz groß – Polarisatoren für UV, VIS und IR,* Photonik 3/2004, S. 70

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