Dual wavelength DOEs with applications to spectroscopy

Basic Technology Research Programme — A 1000 micro-emitters per square millimetre — RESEARCH COUNCILS UK

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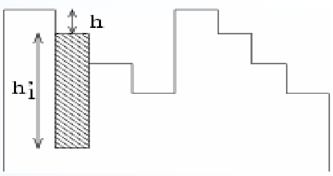
Abstract

There has been considerable work carried out in the design of dual wavelength DOEs. We present an algorithm suitable for the design of such devices with an arbitrary maximum phase delay and number of quantisation levels. Modelled and experimental results are presented together with a design configuration with potential applications to pump and probe separation.

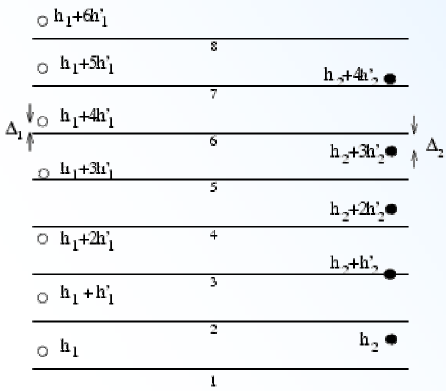
Introduction

An area of considerable research activity has been the development of DOEs which produce different patterns depending on the wavelength of the incident light. This is a challenge as these elements are inherently wavelength specific. There have been two approaches used in overcoming this problem. The first is to design DOEs for operation in the Fresnel region.[1]



The disadvantage of exploiting Fresnel region mechanisms is that the image becomes very sensitive to the position of the image plane. To overcome this, Fraunhofer region methods have been developed. Dammann [2] first introduced the use of phase delays beyond 2π to give the required extra degree of freedom, this is illustrated above where adding h_1'(equivalent to a phase delay of 2π at λ_1) does not change the effective phase at the primary wavelength. However at the secondary wavelength 2 different effective phase values are available.

Method



Step 1 of our algorithm determines the optimum unquantised profiles for each wavelength and its associated pattern. This is done using the Gerchberg-Saxton algorithm[3] followed by the modified Iterative Fourier Transform Algorithm (IFTA)[4]. Running this first step gives Φ_1 and Φ_2 the desired phase for $\lambda_1$and λ_2 respectively. These values are converted to depths h_1 and h_2 using the formula

$$h_i = \frac{\lambda_i \Phi_i}{2\pi(n_i - 1)}$$

where n is the wavelength dependent refractive index.

The second step is to find the quantised profile which produces the desired pattern for each wavelength, this is carried out on each pixel separately. The available quantisation levels are then defined, illustrated by numbers 1-8 in the diagram. h'_1 and h'_2 are depths equivalent to phase delays of 2π at $\lambda_1$and λ_2. Adding multiples of h'_1 to h_1 and h'_2 to h_2 give alternative etch depths which produce the same effective phase delay.

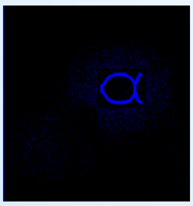
It is highly unlikely there is an exact solution which fits for both Φ_1 and Φ_2, for each pixel we select the level which minimises quantisation error, Δ defined as

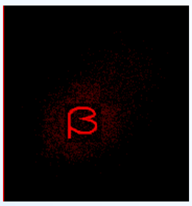
$$\Delta = \max\left|\phi_{L,i}^{eff} - \Phi_i\right|$$

where $\phi_{L,i}^{eff}$ is the effective phase for level L at wavelength λ_i, calculated by removing multiples of 2π.

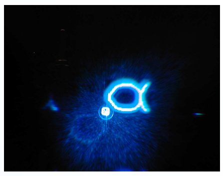
Results

Modelled results for a design producing the symbol α at 470nm and β at 635nm are shown below. The design uses 16 quantisation levels and has a maximum phase at 470nm of 8π.

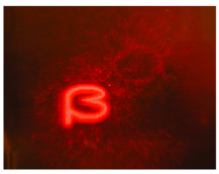




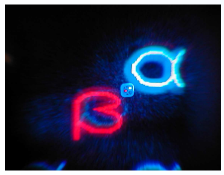
Experimental results are shown below. The same design as used in modelled section has been fabricated and illuminated with LED light at the design wavelengths. The images are captured using a standard digital camera.



Illumination by 470nm source



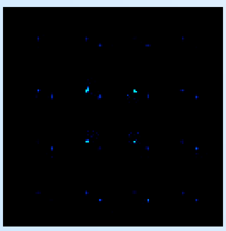
Illumination by 635nm source



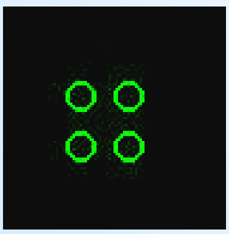
Simultaneous Illumination by 470nm and 635nm sources

Applications to Spectroscopy

The method described above can be used to design DOEs suitable for pump and probe separation. The modelled outputs shown below illustrate a configuration which could be used in the separation of 370nm light from UV micro-LEDS and 532nm light from the excitation of standard fluorescent compounds used for **DNA** sequencing.



Illumination by 370nm source



Illumination by 532nm source

Conclusion

We have demonstrated a successful design algorithm for dual wavelength DOEs which works with arbitrary maximum phase depths and permits any number of quantisation levels. Furthermore a DOE output configuration has been introduced which illustrates the possible application of such devices in the separation of pump and probe light sources for experimental measurement.

References

1. J.R. Sze and M. H. Lu, "Design and fabrication of the diffractive phase element that synthesizes three-color pseudo-nondiffracting beams," Optical Engineering **41,** 3127-3135 (2002).
2. H. Dammann, "Color separation gratings" *App. Optics* **17**, 2273-2279, (1978).
3. R. W. Gerchberg and W. O. Saxton, "A practical algorithm for the determination of phase from image and diffraction plane pictures", Optik **35**, 237-246, (1972)
4. J.S. Liu and M.R. Taghizadeh, "Iterative algorithm for the design of diffractive phase elements for laser beam shaping," *Optics Letters* **27,** 1463-1465, (2002).