

# King's College London

UNIVERSITY OF LONDON

This paper is part of an examination of the College counting towards the award of a degree. Examinations are governed by the College Regulations under the authority of the Academic Board.

M.Sci. EXAMINATION

CP/4755 Optical Information Processing

Summer 2001

Time allowed: 3 Hours

Candidates must answer **THREE** questions.  
No credit will be given for answering further questions.

The approximate mark for each part of a question is indicated in square brackets.

You must not use your own calculator for this paper.  
Where necessary, a College calculator will have been supplied.

**TURN OVER WHEN INSTRUCTED**  
2001 ©King's College London

## Answer THREE questions

1) With the aid of suitable diagrams, describe the properties of

a) the Pockels cell

[4 marks]

and

b) the Kerr cell.

[4 marks]

What are the relative advantages of each compared with the other?

[2 marks]

Explain what is meant by the term *half wave voltage*.

[2 marks]

For each type of device, give one example application, where the device might be deployed in an optical system.

[3 marks]

Describe two principal ways in which an electric field may be applied to a Pockels cell and state how the forms of the expressions for the half-wave voltages differ for each of the configurations.

[5 marks]

The electro-optic material KDP has an electro-optic tensor which can be written in the form:

$$\bar{\bar{r}} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ r_{41} & 0 & 0 \\ 0 & r_{41} & 0 \\ 0 & 0 & r_{63} \end{pmatrix}$$

where  $r_{xx}$  denote the relevant electro-optic coefficients for the tetragonal crystal class. Derive an expression for the half-wave voltage when the field is applied longitudinally.

[7 marks]

Given that the refractive index of KDP is 1.5 and the tensor element  $r_{63}$  has the value  $-10.5 \times 10^{-12} \text{ m V}^{-1}$ , estimate a value for the half wave voltage for light of wavelength 633 nm.

[3 marks]

- 2) Explain the principles of light diffraction from an acousto-optic modulator, distinguishing between the Raman-Nath and Bragg regimes.

[8 marks]

For both regimes, sketch curves of the intensities of the diffracted beams versus the peak optical phase change induced by the optical wave.

[5 marks]

An optical beam of wavelength  $\lambda = 633 \text{ nm}$ , propagating within an acousto-optic medium, passes through an acoustic column  $1 \text{ cm}$  wide, travelling with a velocity of  $1500 \text{ m s}^{-1}$ . Calculate the values of the acoustic frequencies below and above which diffraction occurs in the Raman-Nath and Bragg regimes, respectively.

[10 marks]

Describe, using suitable diagrams, how an acousto-optic cell may be used to perform real-time, radio frequency, spectral analysis.

[7 marks]

- 3) Explain what is meant by a *thin amplitude hologram* and a *thin phase hologram* and state their relative merits.

[5 marks]

Explain the method of *cell orientated* hologram design as developed by Lohmann and Brown. What are the main limitations of this approach to hologram design? Describe the methods of *error diffusion* and *directed binary search*.

[10 marks]

A computer-designed hologram is to be used to redistribute the light from a single laser beam into a square array of Gaussian beamlets in the far field. The requirements are to achieve a high degree of uniformity in the intensity of the spot array, a high numerical aperture and a high diffraction efficiency ( $\approx 70\%$ ), while simplifying issues associated with fabrication. Explain the steps you would take to design this hologram, stating the significant considerations at each stage.

[15 marks]

- 4) Explain what is meant by the term *intensity dependent non-linear optical effect*.  
[1 mark]

With the aid of a suitable diagram, explain how a Fabry-Perot etalon interference filter may be constructed to exhibit all-optical switching.

[4 marks]

The mirrors in a Fabry-Perot etalon are separated by a dielectric spacer of thickness  $\Delta$  and average refractive index  $n$ . Show that, for low light levels, the transmission characteristic for light of wavelength  $\lambda$  is given by

$$I_t = \frac{T^2}{(1-R)^2 \left[ 1 + \frac{4R}{(1-R)^2} \sin^2 \left( \frac{\phi}{2} \right) \right]}$$

where  $T$  and  $R$  are the transmittance and reflectance coefficients of the mirrors used in the device and  $\phi = \frac{2\pi n \Delta}{\lambda}$ .

[7 marks]

Sketch this transmission characteristic as a function of  $\phi$ . Sketch also the transmission characteristic when the light intensity is relatively high.

[3 marks]

Explain what is meant by a *photorefractive nonlinearity* and discuss the main advantages of using photorefractive materials in opto-electronic information processing systems.

[5 marks]

Describe, using appropriate diagrams, how an opto-electronic system may be used to implement an *inner product* operation.

[5 marks]

Show how this concept may be extended to the opto-electronic implementation of a *Hopfield model* of a neural network and explain its uses.

[5 marks]

- 5) In a particular optoelectronic system it is desired to perform the following geometrical transformations ( $f(x, y) \rightarrow f(r, \theta)$ ) upon an input image contained in the  $x - y$  plane:

$$r = \sqrt{x^2 + y^2}, \quad \theta = \arctan\left(\frac{y}{x}\right) \quad (1)$$

and

$$M(u) = \int_0^\infty f(x)x^{u-1}dx. \quad (2)$$

Explain the purposes of these transformations in the context of an optoelectronic pattern recognition system.

[7 marks]

Show that transformation (2) can be represented as a Laplace transform by an appropriate change of variable.

[5 marks]

Describe briefly, with the aid of a suitable diagram, a schematic optoelectronic pattern recognition system which implements the above transformations.

[13 marks]

Describe the information that is contained in the output plane of such a system.

[5 marks]