King's College London

UNIVERSITY OF LONDON

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

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:

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

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 $\times 10^{-12}$ 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 $\lambda = 633$ nm, propagating within an acousto-optic medium, passes through an acoustic column 1 cm wide, travelling with a velocity of 1500 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 Δ and average refractive index n. Show that, for low light levels, the transmission characteristic for light of wavelength λ is given by

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

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 ϕ. 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:

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

and

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

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]