ENGINEERING TRIPOS PART IIB

Friday 27 April 2012 9 to 10.30

Module 4B11

PHOTONIC SYSTEMS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

tdw04

1. (a) A hologram, illuminated by a laser and a positive focal length lens, is used to create a replay field captured by a digital camera. Sketch the optical system, clearly labelling all the parameters involved in creating a replay field with minimal optical distortion. State any assumptions made. [20%]

(b) Explain what is meant by the term *apodisation* with reference to the system you sketched in part a). Why is apodisation a critical issue when considering the applications of holographic fibre to fibre switching and holographic image projection? [30%]

(c) The laser used to illuminate the hologram in a fibre to fibre holographic switch has a finite linewidth $\delta\lambda$. Explain how this linewidth affects the replay field generated by the hologram and the effectiveness of the switch. How could this effect be exploited in optical switching? [30%]

(d) Briefly explain how a hologram could be used to generate a full colour projected image using three lasers (λ = 410 nm, 532 nm, 650 nm). Why is this an advantage over existing image projection systems? Calculate the correction required to perform this function. [20%]

2 (a) Describe how the properties of a planar aligned nematic liquid crystal can be used to modulate the phase of a light source. Clearly list the parameters that are required to perform phase modulation and sketch the orientation of a reflective cell structure. [30%]

(b) One of the main limitations of the nematic liquid crystal phase modulator is its inherent polarisation dependence. Explain why this limitation occurs and why simple solutions such as the twisted nematic structure do not solve the problem. [20%]

(c) Jones matrices are often used to model the propagation of polarised light through bulk birefringent material. Given the generalised format of an optical retarder, W (below) with retardance Γ and orientation with respect to the vertical axis of ψ, derive an expression for a quarter waveplate oriented at 45 degrees to the vertical axis.

[15%]

(d) Using the result from part c) show how a quarter waveplate can be used to make a reflective planar nematic liquid crystal cell polarisation insensitive. [35%]

$$W = \begin{pmatrix} e^{-j\Gamma/2}\cos^2\psi + e^{j\Gamma/2}\sin^2\psi & -j\sin\frac{\Gamma}{2}\sin(2\psi) \\ -j\sin\frac{\Gamma}{2}\sin(2\psi) & e^{j\Gamma/2}\cos^2\psi + e^{-j\Gamma/2}\sin^2\psi \end{pmatrix}$$

3 A Mach-Zehnder interferometer vapour sensor is constructed by sandwiching two parallel slab waveguides (core thickness $2a$, core separation $4a$, $a = 5$ μm, $n_1 = 1.500$, $n_2 = 1.498$), as shown in Figure 1. The two arms are connected at either end by symmetrical and adiabatic 3 dB Y-junctions. One of the two interferometer arms has a 100 μm length section of its core replaced by a variable refractive index material. This material has an intrinsic index of 1.5, which increases in the presence of a test vapour. The device is illuminated with light at a wavelength of 1330 nm.

(a) Derive an expression for the recombined intensity (power output per unit area) as a function of the phase difference ($\Delta\phi$) between the two arms. [25%]

The device is now cut along the line XY indicated in the diagram, enabling light from the two arms to exit, diverge and interfere with each other.

(b) What percentage change in the refractive index would cause the central maximum of the resulting far-field interference pattern to shift by 1°? [25%]

The electric field amplitude of the fundamental mode propagating along the input arm can be described by the following expressions:

$$E(x,z) = A\sin(\kappa_1 x)\exp(-j\beta z) \quad \text{for } -a \le x \le a \quad \text{(in the core)}$$

$$E(x,z) = B\exp(-\kappa_2 x)\exp(-j\beta z) \quad \text{for } |x| \ge a \quad \text{(in the cladding)}$$

where $\kappa_1 = k\sqrt{n_1^2 - n_{eff}^2}$ and $\kappa_2 = k\sqrt{n_{eff}^2 - n_2^2}$.

(c) Derive separate expressions (in terms of A, B, a, κ_1, κ_2) for the total power per unit area within the core and the cladding of the input arm. Hence show that the total power in the cladding is 0.04 % of the total power in the core. (You may assume an effective refractive index, $n_{eff} = 1.499$). [50%]

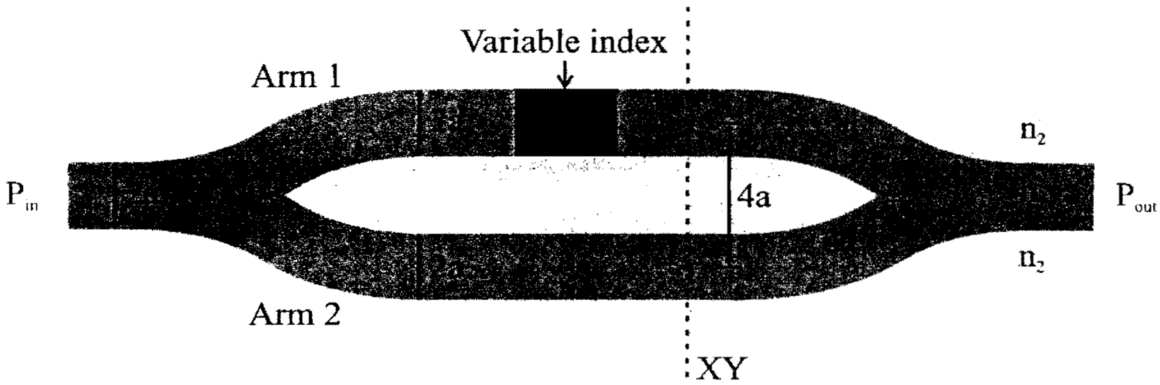

Figure 1

(TURN OVER

4 (a) Sketch a general diagram to show the operation of a joint transform correlator (JTC). Describe the role of each component in the system and suggest a way in which they could be implemented optically. [40%]

(b) Given a square law non-linearity based JTC with a reference object *r(x,y)* located at a position $[0, y_1]$ and an unknown object *s(x,y)* located at $[x_2, -y_2]$, calculate the location of all the correlation peaks in the output plane of the correlator. State any assumptions made. [20%]

(c) If a second object *p(x,y)* is placed at a position $[x_3, -y_3]$ in the unknown input along with *s(x,y)* in part b), find the new location of the correlation peaks. [20%]

Explain why the detection of these correlation peaks is no longer trivial and suggest a possible solution to the problem. [20%]

END OF PAPER