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WINTER COLLEGE ON
LASER PHYSICS: SEMICONDUCTOR LASERS
AND INTEGRATED OPTICS

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INTEGRATED OPTICS, MATERIALS AND PROCESSING TECHNIQUES

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Integrated Optics, Materials and Processing Techniques

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1. Thin Films

Thin films are relevant to planar, guided-wave, optics – 'integrated optics' – in several different ways.

1.1 Thin-film waveguides

Firstly, and most obviously, light may be guided in thin-films of material at wavelengths where the material is sufficiently transparent. As you all now know, the primary requirement on the film as waveguide is that it has a higher refractive index than the substrate or intermediate layers on which it has been deposited – and higher than any subsequently deposited layer. This need for a high refractive index can, however, be by-passed in several ways, if need be:

(i) A lower index layer of sufficient thickness may be used to buffer (isolate) the guiding film from a lossy substrate or a lossy overlayer.

(ii) Over sufficiently short distances, losses due to leakage into immediately adjacent high index or lossy regions may be acceptably small – if the propagating modal rays are incident at sufficiently glancing angles on the interface between the guiding film and adjacent medium.

(iii) One can create Bragg-grating type mirror structures along the length of the guide.

1.1.1 Epitaxial III-V semiconductor films

Clearly one of the most important types of thin-film waveguide structure occurs in heterostructure semiconductor lasers – and in other semiconductor-based optical waveguide devices using similar technology. Very high-quality epitaxial single-crystal growth techniques are involved in such thin-film optical waveguides – techniques such as metallic organic chemical vapour deposition (MOCVD), molecular beam epitaxy (MBE) and other similar and related techniques. One should note that liquid phase epitaxy (LPE), which is still very popular as a technique for making semiconductor laser wafers, is usually considered unsuitable for integrated optics because of growth non-uniformity.

1.1.2 Amorphous (glass) films

Thin-film optical waveguides of an essentially passive nature may be provided by using amorphous or glassy materials. Some of the pioneering work in 'integrated optics' used films of r.f. sputtered glass (e.g. Corning 7059) deposited on soda-lime glass substrates (i.e. ordinary commercial microscope slides). With skill and care, propagation losses at the usual experimental wavelength for this early work (the 632.8nm He-Ne laser wavelength) could be reduced to approximately 1dB/cm – a gigantic figure in comparison with the sub 1dB/km losses routinely achieved (admittedly at longer wavelengths) in modern glass silica optical fibre.

Mention of glass fibres provides a pointer to one approach to thin-film glass waveguides which we propose to examine in somewhat more detail – the adaptation of the vapour-phase deposition techniques used to fabricate optical fibre-preforms for planar film waveguide purposes.

Glass is, as recent work on fibre lasers and non-linear device effects in fibres has clearly shown, by no means necessarily merely a passive propagation medium – and planar glass waveguide structures are certainly capable of providing a vehicle for similar device effects.

1.1.3 Oriented polycrystalline films (inorganic)

Thin films of oriented polycrystalline material, e.g. sputtered zinc oxide (ZnO) and evaporated cadmium sulphide (CdS) have been investigated for optical waveguide devices exploiting the linear electro-optic (Pockels) effect. The advent of a good quality diffusion technology for waveguide fabrication in single-crystal lithium niobate has to a great extent removed interest in oriented polycrystalline inorganic films.

1.1.4 Organic films

In recent years, however, various types of organic material have been investigated for thin-film optical waveguides. In fact, waveguides using organic films such as photoresist, plasma-deposited polymers, liquid crystals and Langmuir-Blodgett (LB) layers have received some attention over quite a long period of time. Recently, increased interest has arisen for several reasons:

(i) the very large polarisability/electro-optic susceptibilities shown by some organic materials at the molecular level,

(ii) improvements in film-deposition technology,

(iii) increasing interest in non-linear optical waveguide device effects,

(iv) recognition that the strength of the electro-optic effect available from inorganic materials such as lithium niobate is still rather small – leading to device lengths and/or voltage requirements which are somewhat excessive.

In this lecturer's view, whatever their long term promise, organic film materials suffer from durability problems, fabrication problems (e.g. electrode-patterning on already-deposited layers) and from massive reductions in the strength of the 'electrooptic' effect(s) in going from individual molecules to complete, consolidated layer structures. The eventual pay-offs may well, however, justify the anguish and woe on the way!

2. Other applications of thin-films in integrated optics

2.1 Diffusion sources

While diffusion technologies are favoured e.g. for waveguide formation in lithium niobate, the diffusion source may well be a thin layer – e.g. of the metal titanium – dpeosited by electron-beam evaporation or sputtering. Similar approaches are also possible in glass or silica. Questions of source film quality may well arise.

(i) how pure is the film – and does contamination, e.g. by iron in titanium, affect waveguide properties undesirably?

(ii) the polycrystalline/quasi-epitaxial (?) nature of the film nucleation and growth behaviour,

(iii) the edge quality of lithographically defined stripes used as sources for diffused stripe optical waveguides.

2.2. Electrode and Contact Layers

Active integrated optics may alternatively be thought of as guided-wave electrooptics

or guided-wave optoelectronics.

For semiconductor devices in this field, the nature of the contact made between metal electrode films and the surface of the semiconductor is crucial. Ohmic contacts to either p-type or n-type semiconductor regions with various different bandgap energies and surface conditions may well be required both for high-current devices such as semiconductor lasers and for low-current, reverse-biased, structures such as photo detectors or electrooptic/electroabsorption modulators. Here, the standard approach is, e.g. to use a multiple gold-germanium-nickel multilayer on n-type gallium arsenide (GaAs). In this multilayer combination, the gold provides the required high sheet conductivity for even current distribution, germanium acts as a dopant, diffusing into a shallow region at the semiconductor surface during an elevated temperature annealing process and nickel acts as a high melting temperature protective blocking layer. Directly rectifying (Schottky) contacts may also be required in optoelectronic semiconductor metal films, e.g. of gold or platinum.

For electro-optic waveguide devices on materials such as lithium niobate, electrodes patterned in single evaporated metal layers of moderate thickness (between, say, 0.3μm and 3μm) are required. It is natural to use aluminium in such applications – since aluminium is cheap, easy to evaporate, has high conductivity and aluminium can readily be formed into complex patterns with good edge quality by lithographic etching or lift-off processes.