Monosilane embedded nanocomposite possessing variable in plane index of refraction (*VIPIR*™) to construct complex waveguide optical systems.

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Abstract: We are reporting on the development of a nanoengineered materials, a monosilane nanocomposite. The material undergoes large change in index of refraction (> 1.0) with photoexposure that enables complex optical structures inegration in waveguide form.

OCIS Codes: 160.4670 Optical Materials; 230.7390 Waveguides, Planar

Introduction

The incorporation of novel materials in Si based microelectronic technology brings optical network benefits to chip to chip communication. Once economically achieved, silicon microcircuits will be able to capitalize on the benefits of optical communication (large bandwidth, EMI/RFI immunity, speed, etc.) whether between chips physically located adjacent to each other in a multi chip module (MCM), on different boards in a system, or between systems separated by considerable distances and either optically connected through guided wave devices or free space optical interconnection. We have developed a self assembled monosilane nanocomposite which possesses unique applicability to the construction of microphotonic circuits. Through exposure to deep ultraviolet radiation, large changes in as deposited index of refraction can be induced (i.e. > 1.0). The ability to produce materials with Variable In Plane Index of Refraction (***VIPIR™)*** permits microphotonic designs to be constructed that are difficult or impossible to construct by conventional means.

Experimental Results

Ionic Systems Model DSN plasma deposition system possesses dual reaction chambers and dual reactant inlets. Results indicate that it is possible to manufacture photosensitive films with a non organic silicon donor reactant and an organic donor reactant. By so doing, the deposited film properties are able to be altered to achieve optimum photosensitivity. Work to date indicates that the ability to use separate organic donor materials and silicon donor materials allows considerably more flexibility in the stoichiometry of the deposited materials than possible with single component organosilicon reactions. The monosilane embedded nanocomposite material provided a family of index of refractions, as deposited, and photosensitivities. Deposition conditions and organic components are varied to produce higher or lower as deposited index of refraction, photosensitivity and increase or decrease contrast as deposited versus after photoexposure. In addition, organic cocktails can be mixed to enhance properties. Typical results, as shown in Fig. 1, are given in the table below with deposition conditions:

Table 1. Deposition conditions and photosensitivities versus exposure dosage.

Component	EGA	TLI	EGA	EGA	TLI
% of Silane	50%	50%	45%	45%	30%
Silane Flow	50cc/min	50cc/min	20cc/min	60 cc/min	50 cc/min
Power	200 Watts	200 Watts	100 Watts	100 Watts	400 Watts
Deposition Duration	2200 sec	2200 sec.	2200 sec.	2200 sec.	2200 sec.
Exposure Dosage (mj/cm^2)					
0 (As Deposited)	1.949	1.669	1.787	2.718	1.726
100					1.587
150	1.959	1.604	1.747	1.966	
200					1.578
300	1.799	1.594	1.718	1.713	1.543
450	1.73	1.589	1.68	1.654	

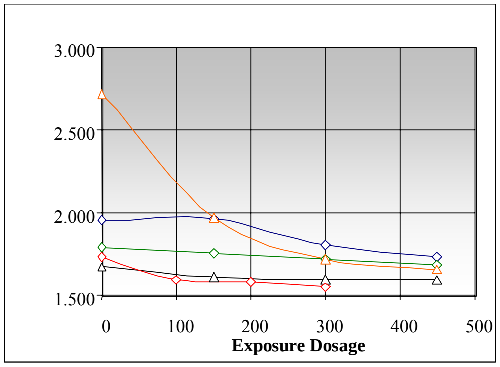

Fig. 1. Index of refraction of representative materials versus exposure dosage.

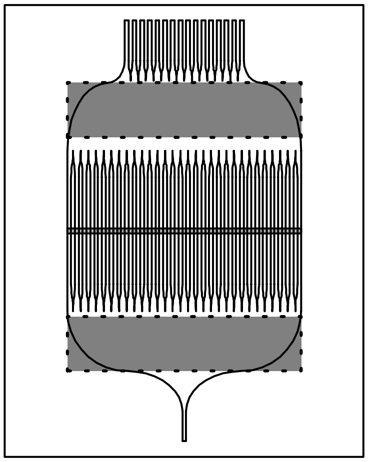

Fig. 2 VIPIR™ enabled one to sixteen channel AWG with half wave plate polarization compensation. AWG measures 0.11 cm in width , 1.5 cm in length and has an area of 0.16 cm^2.

VIPIR™ Enabled AWG Design Issues

Arrayed Waveguide Gratings (AWG) are popular as wavelength demultiplexers for WDM applications[1-2]. They are capable of precise demultiplexing of a large number of channels with relatively low losses. The device consists of two slab waveguide star couplers (also known as free propagation regions), connected by a dispersive waveguide array. Light propagating in the input waveguide will be coupled into the array via the first star coupler. The array has been designed such that for the central wavelength of the demultiplexer the optical path length difference between adjacent array arms equals an integer multiple of the central wavelength of the demultiplexer. As a consequence, the field distribution at the input aperture will be reproduced at the output aperture. Therefore, at a desired wavelength, the light will focus in the center of the image plane (provided that the input waveguide is centered in the input plane). Appropriate positioning of output waveguides on the second slab waveguide star coupler permits the resolution of the individual component wavelengths in the optical data stream.

In a conventional design, a shorter optical path is produced with a shorter physical path, and vice versa, using fixed in plane index of refraction dielectrics. Using Variable In Plane Index of Refraction (***VIPIR™)***, a shorter optical path can be provided with a lower index of refraction material. A longer optical path can be provided with a higher index of refraction material. Physical dimensions of the individual waveguides can now be equalized with the index of refraction variation producing the different optical path lengths. The arrayed waveguide grating produced by ***VIPIR™*** now takes on a very different shape as modeled in Fig. 2. The ***VIPIR™*** approach results in a 85% reduction in area from the conventional Full AWG and a 96% reduction in area from the commonly produced Flat AWG configuration.

VIPIR™ Enabled Device Optimization

Polarization mode dispersion (PMD) has emerged as one of the critical hurdles for next generation high bit rate transmission systems. PMD is caused by different propagation speeds along the two principal states of polarization of a fiber or waveguide. Since the birefringence of a material changes along the length of the link, the effects of PMD are random and time varying [3,4]. We will discuss how the ability of ***VIPIR™*** to embed optics, in this case to provide polarization independence, in the waveguide structure of an AWG. Several methods can be applied for eliminating the polarization dependence of the response of an AWG due to waveguide birefringence. Five different methods will be discussed

1) *Nonbirefringent Waveguides:* The most obvious way to make a AWG polarization independent is by eliminating the birefringence of the waveguide. This can be done by making the waveguide cross section square if the index contrast is the same in the vertical and lateral direction as, for example, in buried waveguide structures. Small deviations of the square shape, for example due to nonperfect control of the waveguide width, will disturb the polarization independence. If the index contrast

between core and cladding is high the tolerance requirements on waveguide width control become impractically tight [5].

2) *Order Matching:* The first attempt to make AWG's polarization independent was based on matching the FSR to the polarization dispersion [6-10]. A disadvantage of this method is that the total wavelength span available for the WDM channels is limited by the polarization dispersion, which is on the order of 4-5 nm for conventional InGaAsP-InPH structures. Another disadvantage is that the exact value of the polarization dispersion is very sensitive to variations in layer composition and thickness, which makes it difficult to obtain a good match.
3) *Dispersion Compensation:* In semiconductor-based AWG's a broad-band solution for the polarization dependence problem is found in compensation of the polarization dispersion by inserting a waveguide section with a different birefringence in the phased array [11,12]. A disadvantage is that this approach is very sensitive to film thickness and waveguide width, so that the compensation requires tight control of waveguide parameters and the compensation section can become excessively long.
4) *Polarization Splitter:* Another method for obtaining polarization independence is by applying a polarization splitter at the input. Due to the polarization dispersion the position of the local spot in the image plane for TE polarization is shifted relative to the TM-polarized one. If the distance between the TE and the TM-polarized receiver in the object plane is chosen equal to the polarization dispersion in the image plane the TE and TM-polarized signals will locus on the same position. Once again, tight material control is required and this method does not apply to *N X N* devices.
5) *Halfwave Plate:* A very elegant method of providing polarization independence is the insertion of a λ/2-plate in the middle of the phased array. Light entering the array in TE-polarized state will be converted by the λ/2-plate and travel through the second half of the array in TM-polarized state, and TM-polarized light will similarly traverse half the array in TE-state. As a consequence TE- and TM-polarized input signals will experience the same phase transfer regardless of the birefringence properties of the waveguides applied. This method was proposed by Takahashi *et al.* and using polyimide halfwave plates but they have a thickness of more than 10µm, and are only applicable to waveguide structures with a small numerical aperture (NA) that can bridge this distance with small diffraction losses[12]. VIPIR easily embeds a halfwave plate in an AWG as shown in Fig. 2.

Conclusion

We have shown the results from the formation of a new class of materials, a room temperature deposited self assembled monosilane embedded nanocomposite that exhibits large change in index of refraction versus exposure to deep ultraviolet radiation. We have further shown that this material/process enables the optimization of microphotonic structures, through reducing path lengths and reducing effects such as polarization mode dispersion, and increases micro optical integration through embedding optical components, such as half wave plates, conveniently in photonic waveguide structures.

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