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Optimization of the formation process of dielectric microwaveguides on the basis of polymer/SiO_2/Si systems using ion irradiation

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Abstract

Physical as well as mathematical and technological aspects of the optimization for the forming process of dielectric microwaveguides on the basis of polymer/SiO_2/Si systems with the implementation of ion irradiation technology are presented. The procedure of choice of bombarded ion parameters is presented. This information allows one to simplify the development of technological aspects of stepped and gradient microwaveguides formed on the basis of a considered system.

Keywords: Ion irradiation; Integral optics; Optical waveguides; Polymer materials; Spectroscopic and laser ellipsometry

1. Introduction

Presently, in the technology of integrated optics (IO) and optoelectronics, hybrid multilayer systems are used widely for providing adequate device functioning [1]. The hybrid microwaveguide structures are of special interest [2]. They are polymer/SiO_2/Si [3], polymer/Ta_2O_5/polymer [4] systems and compositions on the basis of metallized polyimide films [5]. Polycarbonates [6], fluorinated polyimides [7], CR39, HIRI [8] and other polymer compositions [9] are used as the polymer materials. Irradiations by light ions of high energy are used for the formation of the required profile (stepped or gradient) of refractive index. The structures polymer/SiO_2/Si-substrate are of the utmost interest from a practical point of view, especially if energies introduced into microwaveguides on the basis of these structures are not very high. The aim of the present paper is to develop the physical as well as mathematical aspects of optimization for the formation process of

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dielectric microwaveguides on the basis of polymer/SiO_2/Si systems with the use of ion beam processing combined with high-resolution photolithography.

2. Materials, calculations and discussion of results

As the waveguide layer in a polymer/SiO_2/Si-substrate system, polymers having higher refractive index than SiO_2 can be used. The modification of optical properties of such polymers as polymethylmethacrylate (PMMA) or polystyrene (PS) by ion irradiation can also be used [10–12]. Polyimide compositions with approximate formula $[C_{22}H_8O_5N_2]_n$ are usually chosen as polymers having a high enough refractive index. This type of compound has high thermal stability, but it does not have high transparency in the visible region and its adhesion to the number of electronic materials leaves much to be desired. Therefore, ion irradiation can be treated as the preferable processing to increase the refractive index of PMMA [10] or polymethacrylmethylimide (PMMI) [11]. The important requirement of materials of dielectric microwaveguides is a value of optical losses that must be less than 1 dB/cm. This requirement narrows considerably both the set of possible initial materials and the possibilities of ion beam technologies because of the essential increase of extinction coefficient (k) of polymers with irradiation fluence. The properties of some perspective organic materials are listed in Table 1. These data illustrate nonlinear optical properties for polyvinylcarbazole [13]: $n = n_0 + \alpha I$, where I is the irradiation intensity, n_0 is the refractive index at low values I and α is the proportionality coefficient. The negative photoresist SU-8 is also a very prospective material [14]. It has a good thermal stability up to $T > 200\,°C$. From a technological point of view, it is greatly preferable to use the modern positive photoresists of high resolution such as S1813, SPR135, SPR700 and other compositions on the basis of novolac resins.

One of the basic disadvantages of ion implantation for forming structures with changeable refractive index in depth is a jump of refractive index (n) at the end of the trajectory of moving particles in the region where elastic energy losses dominate. The use of polymer materials as a waveguide layer allows one to settle the problem completely. The ion fluence required for a change of refractive index by 1% is lower by three orders of magnitude [10] than that of non-organic dielectrics [15]. This is achieved by implantation of protons or helium ions which have $[dE/dx]_e \gg [dE/dx]_n$ on the whole acceptable for this technology energy region.

The program SRIM-2003.24 (www.srim.org) was used for the calculation of parameters of implanted particles and deposited energies. This program realizes the Monte-Carlo code (MC) in the application to ion irradiation of amorphous materials. We will deal with the thickness of waveguide films of 1.0 μm and the thickness of a thermally grown oxide layer of 0.7 μm under modeling the ion irradiation conditions for the polymer/SiO_2/Si structures.

Depending on the relation between implanted particle energies and layer thickness in the system polymer/SiO_2/Si, four different types of implanted atom distributions should be noted 1—particles will stop in layer 1 completely; 2—particles will stop basically in layer 2 and partially in layer 1 (or on the contrary); 3—particles will stop in layer 2 with a small "tail" of distribution in the substrate;

Table 1
Summary of organic materials for dielectric waveguides

Material	n	Loss (dB/cm)	Reference	Material	n	Loss (dB/cm)	Reference
Photoresist based on novolac resins	1.58–1.63	2.0	[2,10]	Polycarbonate	1.582	3.0–3.8	[8]
						<1	[6]
Polyvinylcarbazole	—	1	[13]	PMMI	1.50	<1	[11]
SU-8	1.596	0.5–0.6	[14]	Polyimide	1.76–1.82	1–3	[10]
PMMA	1.48	1.0–2.3	[10,11]	Polystyrene	1.57–1.58	0.5–1.0	[10]