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# Alternate Materials for Optical Switching Technology in Optical Communication System

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***ABSTRACT***
*Selection of materials for the purpose of switching operations in present fiber-optic communication systems which operate in the near-infrared region with low attenuation optical windows (850nm, 1310nm, 1550nm and 1625nm) has become an important issue to avoid possible losses during switching and for their compatibility with the present fabrication technologies. Materials which can refract, reflect, transmit, disperse, polarize, detect, and transform electromagnetic radiation in ultra violet, visible or infrared spectral regions are termed as optical materials. They are used for fabricating fibers, small dimensional waveguides and optical elements such as lenses, mirrors, splitters, windows, prisms, polarizers, detectors, and modulators.Their optical properties like refractive index, transparency, spectral dependency, uniformity, strength, hardness, temperature limits, chemical resistivity etc. are determined by microscopic level investigation of interaction between atoms, their electronic configurations and photons. These properties can be altered or controlled by varying the wavelength of the incident light, other parameters like temperature, pressure and in some cases by applying external electric or magnetic fields on the materials.*

***KEYWORDS****; Switching, Alternate, Attenuation, Communication, Compatibility.*

## I. INTRODUCTION

Switching of light signals is either by changing propagating light behavior or alternation of material properties such as refractive index, crystal orientations, etc. While exploring LN optical properties, other materials had also been used by the research community to develop waveguides and fibers to perform optical switching. Materials possessing piezoelectric, electrostatic or ferromagnetic characteristics have been preferred for developing MEMs switches, where switching of light waves is achieved by changing their micro-mirror orientations. The silicon itself is a good choice for integrated optoelectronics applications due to its high refractive index and transparent characteristic at the communication wavelengths. With progress of silicon technology, silicon–on–insulator (SOI) has also immersed as a popular wafer to accommodate the integrated photonic devices and switching circuits. Many III–V group semiconductors, such as GaAs–GaAlAs, are capable of realizing high-speed optical modulators and switches with their EO-effects. Similarly, in photonic crystals, switching of light signals has been achieved by pumping light based alterations in their index- contrast with mechanisms, such as photonic-band gap shift and defect-mode shift. However, with these mechanisms, high pumping intensity is usually required. This problem can be overcome by enhancing the optical nonlinearities in such crystals such as using excited-state interelectron transfer method to perform ultrafast switching with less power consumption. Polymers, InP/GaAs, Si, etc. have been preferred for fabrication of passive waveguides and phase (carrier) modulators due to their transparent behavior for such applications. A large number of organic materials have also been a preferable choice for performing optical switching such as materials possessing LC state over a certain temperature range, through which polarization of the propagating light has been altered using a modulating electric field to fabricate modulators, switches and splitters (Kar, 2000).

This work deals with prominent characteristics of optical materials which makes them suitable for all optical switching. Glass, crystalline materials, polymers, plastic materials, composite semiconductors, synthetic organic crystals etc, are most commonly used materials for fabricating optical devices and elements. A variety of plastic materials has been used for fabricating economical and light but uniquely designed optical elements showing high precision. They are susceptible to microscopic defects (result in light scattering), stresses (birefringence) and temperature variations (change in the refractive index). Many compound semiconductors such as GaAs, GaAlAs, and InGaAsPetc, have been also used to fabricate lasers, light emitting diodes, and photodetectors. Compositions and architectures which are not possible with inorganic materials, synthetic organic polymers such as lithium fluoride, calcium fluoride, and potassium bromide, alkali-halide crystalsetc, have replaced natural crystals to fabricate durable, optically efficient, reliable and inexpensive photonic and optoelectronic devices. Recently, birefringence crystals have also been used for fabricating splitters, modulators, switches etc. These crystals such as $NH_4H_2PO_4$ (ADP), $KH_2PO_4$ (KDP), $KTiOPO_4$ (KTP), β-$BaB_2O_4$ (BBO), $Li_2B_4O_7$, $LiNbO_3$, $LiTaO_3$ etc behave nonlinearly when exposed to the field.

## II. Discussions on Experimental Results

### Proton Exchange Process In the Materials

Proton exchange is used for forming optical waveguides in alternative materials like in Lithium Tantalate ($LiTaO_3$). The following theory for proton exchanged process on the material substrate is mainly taken from technical background and tutorials suggested within waveguide optics modeling software system by Optiwave Inc. 2006. The process of proton exchange typically involves a replacement of Lithium ions ($Li^+$) by hydrogen ions or protons ($H^+$) under specific process environment. There placement introduces a change in refractive index, thus forming a waveguide. The waveguide formation has two stages:

- Basic proton exchange from an organic proton source.
- Annealing post processing.

Basic proton exchange involves the immersion of the material substrate in an appropriate proton source, usually an acid melt and subsequent heating for a couple of hours at temperatures ranging from 150 to 300 °C. Under these conditions, the two ion species counter diffuse, so that material is exchanged between the substrate and the melt.

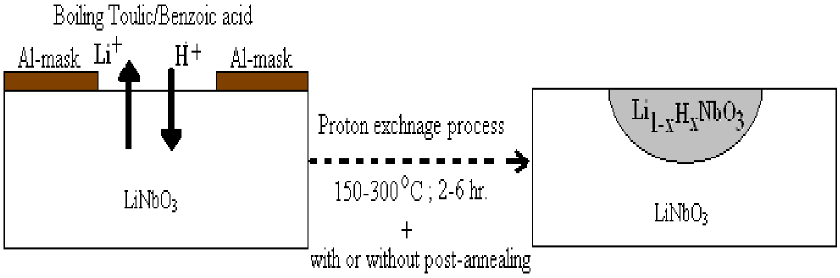

*Figure 1.; Proton exchanged (PE) process within the substrate*

Annealing post processing involves solely heating of the sample. It brings about a redistribution of the Lithium and Hydrogen ions. Proton exchange process on its own leads to a step-function index profile with a change of the refractive index given below:

$$\Delta n_{\mathrm{es}}^{(\mathrm{o})} = \beta[1 - \exp(-\gamma x^{\delta})]$$

where the constants, β=0.1317, γ=3.4576, ∂=1.75 are fitting parameters from experimental data, and x is the normalized $H^+$ fractional concentration. The waveguide depth after the exchange is obtained as

$$D_{\mathrm{v}}^{(\mathrm{o})} = 2\sqrt{(tD_{\mathrm{o}} \exp(-Q/RT))}$$

where *t* is the exchange process time, $D_o$ is the diffusion constant of the proton exchange process, Q is the activation energy, T is the process temperature, and where R is the universal gas constant. The most common sources of hydrogen ions $H^+$ are the benzoic acid and the toluic acid. The exchange parameters of these acids are mentioned within the table 1 below;

Table 1. Data Sheet for Toluic Acid and Benzoic Acid

| *Parameters* | *Toluic Acid* | *Benzoic Acid* |
|---|---|---|
| Temperature range [$^0$C] | 108-263 | 131-142 |
| Diffusion constant $D_0$ [µm$^2$/hr] | $7.02x10^7$ | $8.36x10^9$ |
| Activation energy Q [kJ/mol] | 75.58 | 97 |

Waveguides fabricated with pure melts have been found to be affected by serious problems, the most notable being the degradation in EO–coefficient, a large scattering and insertion loss and refractive index instabilities. The effective solution to this problem is to anneal the samples after the exchange process in order to eliminate the compositional instabilities and to restore the material properties (Nikolopoulos, 1991). Annealing helps avoiding problems related to a high fraction of hydrogen ions in the exchange waveguides. Naturally, the post–exchange annealing process leads to a different refractive distribution of the refractive index, which can be modelled as

$$n_o(y) = n_{eo} + \Delta n_{es}(f(y))(g(x))$$

Where $n_{eo}$ is the extraordinary bulk index of the material substrate, $\Delta n_{es}$ is the maximum refractive index change on the surface, and f(y), g(x) are the distribution functions. The distribution function in the horizontal direction after annealing is approximated in a similar fashion as in the case of Titanium diffused waveguide using the following error distribution function.

$$g(x) = \{\frac{1}{2} erf[\frac{w}{2D_H}(1+\frac{2x}{w})] + \frac{1}{2} erf[\frac{w}{2D_H}(1-\frac{2x}{w})]\}^b$$

Where $D_H$ is the horizontal diffusion length and b is the power of the horizontal distribution function. The distribution function in the vertical direction is defined by the hyper–Gaussian dependence

$$f(y) = \exp[-(y/D_v)^a]$$

Where *a* is the power of the hyper-Gaussian distribution, usually ranging between 11 to 22, and $D_v$ is the diffusion depth after annealing or effective guide depth. It is very much possible that the diffusion depth $D_v$ as well as the maximum refractive index difference after annealing $\Delta n_{es}$ have significantly different values than the ones before annealing. These parameters can be defined on case basis, to control the performance of the designed device. As an example, we quote empirical relationships to calculate $\Delta n_{es}$ and $D_v$ for annealing at 200 and 400°C.

$$\frac{D_v}{D_v^{(0)}} - 1 = bt_a^{\,c}$$

$$1 - \frac{\Delta n_{es}}{\Delta n_{es}^{(0)}} = pt_a^q$$

Whereas $D_v^{(0)}$ is the initial PE depth, $\Delta n_{es}^{(0)}$ is the initial change of the refractive index after proton exchange and b, c, p, q are the fitting parameters, typical value for these are depicted in table 2. The refractive index distribution is strongly dependent on the post–exchange time $t_a$ and the post–exchange temperature $T_a$.

Table 2. Data sheet for values of b, c, p, q at different temperature.

| *$T_a$[°C]* | *b[$hr^{-c}$]* | *c[-]* | *p[$hr^{-c}$]* | *q[-]* |
|---|---|---|---|---|
| 300 | 0.7031 | 0.0754 | 0.2325 | 0.1033 |
| 400 | 1.2884 | 0.7577 | 0.3749 | 0.6574 |

**Material Doping using Magnesium Diffusion Process**

Damages due to photo-refractive effect in suitable melt grown substrate certainly limits it's applications in high optical power devices. A possibility to increase laser damage threshold of the material is to dope with MgO. The diffusion of Mg dopant into the material host induces negative index changes. The process starts by deposition of a stripe of Mg source, usually the oxide of Mg, onto the material substrate. The sample is then heated for several hours, similar to the Ti– indiffusion process. The major differences between the Ti and Mg diffusion processes are as follows:

- Mg distribution constants are negative in contrast to positive values for Ti-diffusion. From the literature data, the constants are approximately one order of magnitude larger than those for Titanium diffusion.
- The power distribution factors for the Mg process are the same for ordinary and extraordinary indices and equal to unity in contrast to Titanium process.
- Different diffusion constants and temperature coefficients.

***Conclusion;*** In telecommunication networks, protection and restoration are collectively called recovery mechanisms. These refer to the mechanisms that are used to minimise or eliminate the downtimes due to failures in optical networks. However,in literature,many works on design and evaluation of protected networks have been reported but due to the complexity of the problems,many articles focus on specific aspects only. Therefore, comparisms between the reported results sometimes are difficult to make. However,with ever increasing bit rates handled by single network elements, the impact of failure is still on the increase hence, protection and restoration schemes become more and more important. Both use spare capacities in the network to restore interrupted traffic; protection uses pre-calculated and pre-assigned protection resources for fast reaction in case of a failure,whereas restoration try to make most efficient use of spare capacities available when failure occures. Restoration is usually slower than protection but is in general more efficient and can deal with unexpected failures.Thus,it is very important that both schemes are applied in network traffic management with different priorities.Therefore, in a connection-oriented network such as the all-optical transport network,shared protection provides the same level of protection against single path failures as dedicated protection with higher potentials of network utilization. Shared protection also provides decent protection with potentially much lower network resources; thus,the network can achieve higher utilization.The shared protection and dedicated protection schemes complement each other to offer more flexible solutions.Only the paths with the most strict protection requirement that need to be dedicatedly protected.The other paths can be protected under shared protection and free up network resources to either support more paths or to protect paths that had no protection schemes before.

The benefits of shared path protection have attracted some research interest especially for the emerging all optical WDM network and proposed a control protocol with various capabilities including shared protection routing for WDM mesh networks.Therefore,this work investigated survivability in wavelenght division multiplexing (WDM) mesh networks and proposed a new network protection algorithm called improved shared-path protection (ISPP) to completely tolerate multi or double –link /path failures. This new algorithm was compared with the previous algorithms for protecting double-link failures such like the SPP and SLP. The advantage of the ISPP is that it allows primary paths and backup paths to share mixed wavelength-links based on its rules in which some primary wavelength-links can be changed to mixed wavelength-links and can be shared by the primary paths and the backup paths. Secondly, some mixed wavelength-links also can be shared by different backup paths for saving resources. Simulation testbed results show that ISPP algorthm performs better resource utilization ratio and blocking probability than the conventional SPP and SLP algorithms. Therefore, if multiple protection paths share common resources,those protection paths should not activate simultanously. In order to achieve this,the routing algorithm must not allow protection paths from sharing common resources if their primary paths have common element in their risk vectors but if a resource is already taken by a protection path,that resource should be shared as much as possible by subsequent protection paths up to the maximum number allowed on that resource.The reason is to reduce the number of total resources taken by protection paths in the network.Therefore,already shared resources should be given high preference for routing protection path.For multiple routing request,they are either processed one at a time or all at once.

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