1994 IEEE Nonlinear Optics:

Materials, Fundamentals, and Applications

July 25-29, 1994

Hilton Waikoloa Village
Waikoloa, Hawaii

Cosponsored by:
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8:00am - 8:25am (Invited)
MA1

EO POLYMER MATERIALS AND DEVICES: FROM RESEARCH TO REALITY

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Polymer nonlinear optical materials offer new opportunities in integrated optics[1]. The large electronic hyperpolarizabilities in certain conjugated organic molecules lead to materials with large, ultrafast optical susceptibilities. In particular, electro-optic (EO) poled polymer materials exhibit low dispersion and low dielectric constants. EO polymer materials have been modulated to 40 GHz[2] and exhibit few fundamental limits for ultrafast modulation and switching. Polymeric integrated optic materials also offer great fabrication flexibility. The materials are spin-coatable into high quality, multilayer films, and can be patterned, metallized, and poled. Channel waveguides and integrated optic circuits can be defined by the poling process itself[3], by photochemistry of the EO polymer[4,5], or by a variety of well understood micro-machining techniques. To date, EO polymer materials have been used to fabricate high-speed Mach-Zehnder modulators[6], directional couplers[7], Fabry-Perot etalons[8], and even multitap devices[9]. Recent developments in EO polyimide materials[10,11] show it is possible to achieve sufficient thermal stability of the aligned state to meet both manufacturing and end-use requirements[12] for such devices. The demonstrated performance of EO polymer materials and devices is now beginning to approach that of inorganic materials, as displayed in Figure 1.

The ultimate advantages of EO polymers, however, may extend far beyond the duplication of inorganic devices. Multilayer structures of EO polymers can be fabricated in large area formats (6-8 inch wafers) with high device packing densities. Furthermore, EO polymer devices can be fabricated directly on electronic substrates and assembled with ICs to create a hybrid optoelectronic package. Finally, the substrate itself can serve as a bench for assembly and integration in a manner similar to standard Si waferboard[13].

FIGURE-OF-MERIT	GaAs	Ti-Lithium Niobate	EO Polymers
EO coefficient r (pm/V)	1.5	31	30
Dielectric constant ε	12	28	3.5
Refractive index n	3.5	2.2	1.6
$n^3 r$ (pm/V)	64	330	123
$n^3 r/\varepsilon$ (pm/V)	5.4	12	35
Loss (dB/cm @ λ=1.3 μm)	2	0.2	0.5
Space-BW product (GHz-cm)	>100	10	>100
Voltage-length product (V-cm)	5	5	10

Figure 1. Comparison of different technologies for integrated optic devices

Planar polymer waveguide technologies have the ultimate potential to gain widespread use in essentially every electronic and fiber-optic system application. Passive components will find use as splitters, couplers, multiplexors, and parallel array connectors in trunk, local loop, wide-area,

and local-area networks. Electro-optic polymer devices have the broadest potential. Applications include external modulation of lasers, fast network configuration switches, optical network units in Fiber-to-the-Home (FTTH), modulator arrays for data networks, filters, couplers, multiplexors, digital-analog and analog-digital converters, and pulse-shapers. The market potential for planar polymer waveguides is very large due to low wafer processing costs and potential to achieve low-cost single-mode fiber-attach and packaging. This means polymers may compete well with other technologies in conventional optoelectronic applications.

Polymer technologies offer new, unique opportunities in electronic systems applications that are not available with other technologies. With polymers, high levels of integration have been demonstrated by using multiple levels of waveguides[14] as well as in-plane and out-of-plane mirrors[15]. The potential for low-cost manufacturing, packaging, and assembly arises from the capability to perform hybrid integration of single-mode components using lithographically-defined registration techniques. This could lead to advanced products such as processor multichip modules with high-bandwidth interfaces between CPU and second-level cache, optical mesh routers for massively parallel computers, and 8-12 bit, high-speed A-D's. EO polymers are unique in offering this level of product potential.

Cost, reliability, performance, and availability are the main drivers for obtaining and sustaining long-term interest in polymers by systems users. Polymer reliability is seen by customers as a major issue, particularly for EO poled polymers. Reliability needs to be proved with extensive test data of the packaged components, following the well-known standards for telecom and electronic components, in general. It is important to note that laser diodes have achieved success in the market, despite their propensity for drift, low-yields, limited lifetime, and failure. The market has accepted "correction" methods for laser diode performance, such as thermo-electric coolers, drift compensation circuitry, and elaborate packaging because the total cost of a laser transmitter has been reduced to acceptable levels in many cases. Similar techniques could be applied to polymer devices but will increase their cost and may reduce their reliability.

Major outstanding issues in EO polymer devices include the reduction of DC drift, reduction of loss, and enhancement of thermal stability. To date, all of these issues have been resolved in EO polymer devices, although perhaps not all at the same time. However, the fundamental reasons for drift or poling decay are sufficiently understood to provide enthusiasts and skeptics alike with optimism for the achievement of commercial specifications for the technology.

What about competing technologies? For passive technologies, glass is the main competitor. $LiNbO_3$ and GaAs waveguides, and direct laser modulation provide competition for electro-optic polymers. Underlying all of this is the inertia of electronic systems designers to change their solutions from wires to fiber-based systems: Whenever possible, electronic solutions will be thoroughly examined and selected, if economically feasible and practical. However, high-end communication in all markets is moving toward utilization of the bandwidth offered by optical fiber, and thus the growth of markets for all optoelectronic devices is inevitable. EO polymers will likely share the market with their inorganic counterparts.

With further development, electro-optic polymers have the potential to far-outdistance inorganic materials in figures-of-merit, and, in fact, already do in some key properties, such as length-bandwidth products. Polymers are not likely to ever exhibit insertion loss as low as glass for passive devices. However, intrinsic performance of polymers, measured against other materials, is not sufficient for judging the potential of the technology. Overall production costs, balanced against performance, will determine the utilization of polymer waveguide technologies.

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Bulk-Type Phase-Matched SHG Devices of Poled Polymers

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Introduction:

Polymeric second-order nonlinear optical (NLO) materials have been studied extensively in recent years for applications in communication and optical signal processing[1-2]. Most of the earlier works were concerned with the synthesis and the general properties such as nonlinear optical coefficients and temporal stability. Only a few studies have been reported on phase matched second harmonic generation (SHG)[3]. In fact phase matching is the first important condition to achieve high conversion efficiency of SHG. It has been proposed that the mode dispersion of fundamental and second-harmonic waves was used to achieve phase matching, in which very precise control of film thickness was required. This is not easy for poled polymer films generally obtained by spin-coating. To avoid this difficulty, the use of Cerenkov radiation and non-collinear light path have been proposed. But in all these methods the obtainable SHG conversion efficiency was limited by the small over-lap integrals for different modes. In order to maximize the overlap integral, the quasi-phase matching (QPM)[4] mthods by altering $\chi^{(2)}$ singal or periodic poling have been proposed. But again the precise control of periodicity should be needed, which is also very difficult. Here we describe, for the first time, bulk phase matched second harmonic generation in poled and drawn polymers, polyurea (PU) by using birefringence. The calculated type-I phase-matching characteristics of a drawn PU was confirmed by experiment.

Experiment and results:

1.Sample preparation

The schematic synthesis of polyurea (PU) is shown in Fig. 1.

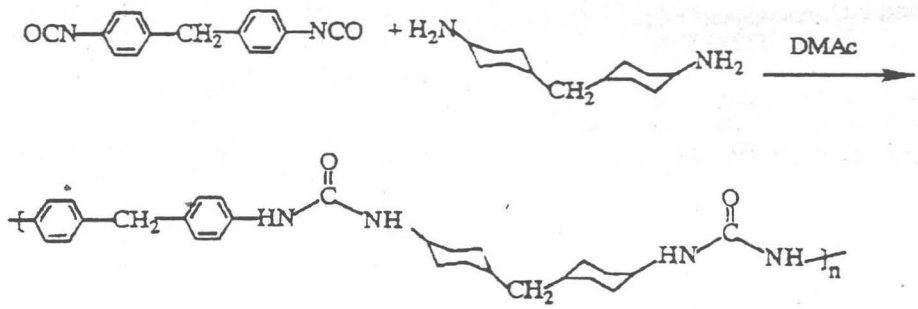

Figure 1. Schematic synthsis of polyurea

2. Polymer geometry and refractive indices

The geometry of polymer and the dispersion of refractive indices vs wavelenths of U1 polymer with draw ratio of 1.4 were shown in Fig.2, and Fig. 3, respectively.

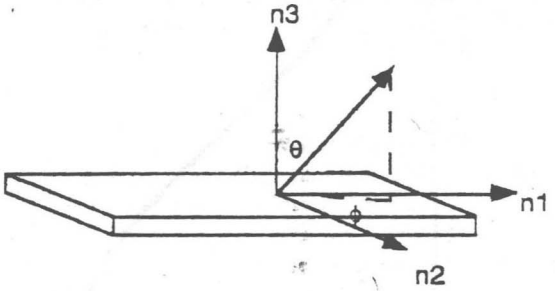

Fig. 2. Geometry of polymer film samples

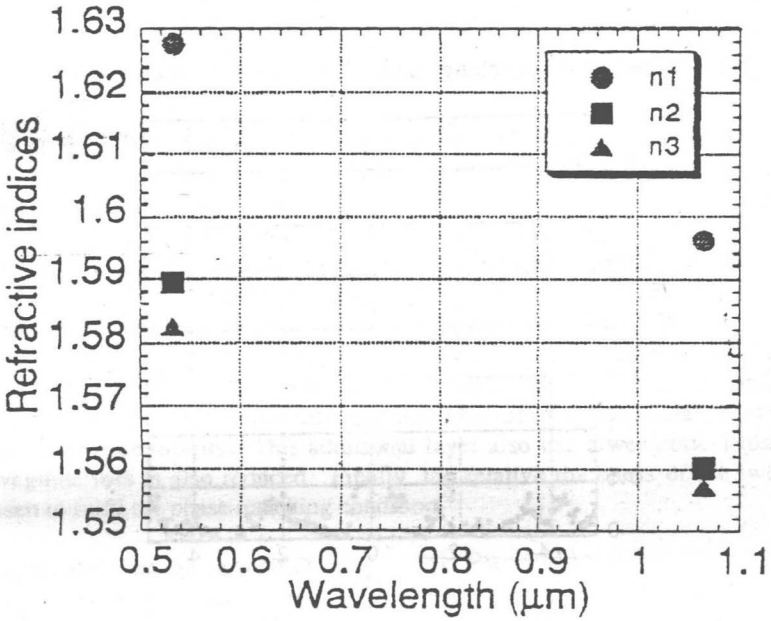

Fig. 3. Refractive indices of poled polymer with draw ratio of 1.4

3.Phase matching experiment

Using the refractive indices of polymer with draw ratio of 1.4, the type I phase matching characteristics has been calculated, the θ and ϕ curve was shown in Fig.4. Cutting a film with θ= 90° and ϕ= 52.6°, the phase matched SHG has been observed in experiment by using a Nd:YAG laser with 1064 nm fundamental wavelength. the results were shown in Fig.5.