

**UNIVERSITY OF SOUTHERN CALIFORNIA
SCHOOL OF ENGINEERING**

**Basic Materials and Fabrication Studies of Advanced
Polymer Opto-Electronics**

AASERT Grant No. F49620-95-1-0445

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FINAL TECHINICAL REPORT

September 1, 1998

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Submitted to:

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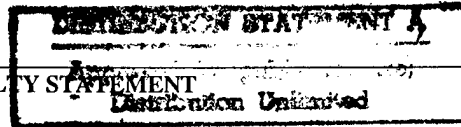
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This report reviews the research under the ASSERT Award for the support of graduate students. The work includes measurements of the linear and nonlinear optical properties of new electro-optics polymer materials developed by the Chemistry Department, applications of these materials to high speed infrared modulators, and a discussion of the issues involved in packaging these modulators. The report also includes a review of work on three dimensional integrated optics using passive polymer materials and a review of the trimming of polymer integrated optical components by photo-bleaching.

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Objective: The objective of this research is to bring the demonstrated advantages of the electrooptic polymers into use in photonic devices and systems. The recent dramatic advances in these materials in terms of their EO coefficients, thermal stability, and ability to fabricate low loss optical waveguides make them prime candidates for high speed optical switches and modulators. The objective is therefore to develop fabrication strategies, prototype device designs and packaging techniques for high speed polymer electrooptic devices and to demonstrate the applications of the polymer devices for ultra-high frequency modulation (50-100 GHz) and for high speed switches (2-3GHz) integrated with semiconductor electronics. An additional goal is to support the EO polymer synthesis research with optical and EO materials measurements.

Progress: During the period of this AASERT award the students supported have contributed to the research and made progress in several areas

New EO Materials: In a close collaboration with Professor Larry Dalton in the Chemistry Department, we have been developing new electro-optic polymers. We have developed a number of procedures for rapidly evaluating the new materials including ATR measurement of the EO coefficients, immersion technique for measuring optical loss, and second harmonic generation during a temperature ramp of the sample to measure temperature stability of the poling. by using a guest-host thermoplastic polymer. *In situ* monitoring of the NLO effects during poling determines the optimum poling procedure and measurement of the EO coefficients by ATR determines the optimum loading. The effects of thermal increases in film conductivity and in photo-conductivity are also monitored.

We performed a thorough and systematic analysis of a 1,3-Bis(Dicyanomethylene)indane (BDMI) chromophore. First, the chromophore nonlinearity was evaluated by studying guest/host systems. Host materials of PMMA, polycarbonate, and polysulfone produced different glass-transition temperature (T_g) systems. Since the best poling efficiency occurred in PMMA, it was selected to determine the optimum doping levels. Chromophore weight percentages ranging from 10% to 40% were doped into PMMA to determine the extent of chromophore-chromophore interaction. The optimum doping level of 30% produced repeatable r_{33} values of 20 pm/V at $\lambda=1.06\mu\text{m}$. Initial attempts of covalently attaching the chromophore as a sidechain to PMMA and polyester yielded nonlinearities of 10 pm/V. Further investigation is underway.

In addition to the BDMI chromophore, other materials have been evaluated. ISX, for example, was incorporated into a polyurethane system at weight percent levels of 20% and 40%, and produced nonlinearities of 9 pm/V. This closely matched absorption data showing a 35% chromophore alignment. In order to achieve this magnitude of poling efficiency in the higher β chromophores (BDMI), initial work has been started on a corona triode poling system. This could potentially provide larger, more uniform voltages across the thin films and enable monitoring of the poling fields.

Recently we have reported a new high- $\mu\beta$ chromophore based on a novel tricyanobutadiene acceptor incorporating a furan-derivative ring, FTC (2-dicyanomethylen-3-cyano-4-{2-[*trans*-(4-N, N-diacetoxyethyl-amino) phenylene-3,4-dibutylthien-5]vinyl}-5,5-dimethyl-2,5-dihydrofuran). The furan ring plays an important role in keeping the conjugation planar and stabilizing the acceptor end of the

chromophore. Also, the two methyl groups on the heterocyclic (oxygen) ring and the two butyl groups on the thiophene ring should prevent the large dipolar chromophores from aggregating which is caused by strong electrostatic interactions in most of the high- μ b chromophores. The interaction between the chromophores may reduce the achievable EO coefficients. The FTC chromophore showed good EO effect ($r_{33} > 55$ pm/V @ 1.06 μ m) in a PMMA-doped polymer system, excellent solubility which is essential for materials processibility, high chromophore thermostability (> 300 °C), and relatively low chromophore absorption maximum resulting in a low optical loss (< 1 dB/cm). To enhance the thermal stability and produce device quality material, we have synthesized hydroxyl functionalized FTC chromophores by adopting a single-end crosslinked polyurethane system. This thermoset polyurethane is used to stabilize the polar alignment of a nonlinear optic polymer. Two crosslinkers, toluene diisocyanate (TDI) and triethanolamine (TEA), were subsequently used to make the covalently attached polyurethanes. In devices operating at 1300 nm the EO coefficient of the thermal FTC containing polymer is ~ 25 pm/V. Figure 1 shows the EO polymer TS-PU-FTC and Figure 2 shows the chromophore absorption spectrum.

Modulator Applications Work has been done to incorporate the new polymers into high speed low voltage infrared modulators. This included studying the effects of poling through different lower claddings (DOW Cyclotene, planarizer, epoxy), waveguide fabrication techniques, and use of an annealed Ti/Au lower electrode for better adhesion during dicing and polishing. Using the TS-PU-FTC polymer we have made Mach Zehnder amplitude modulators with V_{π} of 4.5V. These devices have been tested up to 60 GHz at UCLA. A schematic, with dimensions, of the modulator along with the measurement of V_{π} is shown in Figure 3.

Packaging of polymer photonic devices - The efficient coupling of light from fibers to polymer waveguides is a critical technology. To maintain a high device efficiency most polymer EO devices have a strongly elliptical mode shape while the fiber mode is circular. This mode mismatch typically accounts for 8-10 dB of insertion loss which must be reduced for systems applications. We have developed and demonstrated a practical approach to the fabrication of mode transformers on each end of a polymer EO modulator. Using some recently developed techniques for the fabrication of vertical slopes in polymer layers, we have demonstrated mode taper sections which reduce the coupling loss on each fiber to waveguide transition by ~ 2 dB. Figure 4 show a schematic of the mode taper.

3-D optical integrated circuits - 3D optical integration, i.e. the vertical coupling of several 2D layers of optical integrated circuits is a promising approach to increasing the density of photonic devices and in possibly equalizing optical delays. Polymers are the ideal medium for this application and we have demonstrated some of the key waveguide components to achieve 3D integration, including vertical waveguide bends and vertical waveguide power dividers. The concept of 3D integrated optics and the fabrication techniques for vertical structures are shown in Figure 5

Patterning and trimming of polymer integrated optical circuits by photo-bleaching - Photo-bleaching provides a carefully controlled method to make fine adjustments in waveguide optical structures. We have demonstrated that photobleaching can be used to quickly adjust the power splitting ratio in Y-junctions and the extinction ratio in Mach Zehnder interferometers. This fine adjustment of photonic circuits by photo-

bleaching has good promise for use in the manufacture of photonic circuits. Figure 6 shows the trimming of the Y-branch of a Mach Zehnder interferometer and the instrument of controlling and measuring the trimming.

III. Personnel

Sean Garner, Research Assistant
Araz Yacobian, Research Assistant

IV. Publications and Presentations by AASERT Supported Students

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 15. "Integrated optical vertical polarization splitters using polymers", S. Garner, V. Chuyanov, A. Chen, S-S Lee, W. H. Steier, L. R. Dalton, *Proceedings of SPIE*, Vol. 3278 (1998)
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3. "Integrated optical vertical polarization splitters using polymers", S. Garner, V. Chuyanov, A. Chen, S-S Lee, W. H. Steier, L. R. Dalton, SPIE Photonics West, San Jose, CA Jan. 1998, Session 3278.
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13. "Fabrication of vertical tapers in polymer thin films by oxygen reactive ion etching with a shadow mask for photonic device applications" A. Chen, F. I. Marti-Carrera, S. Garner, V. Chuyanov, W. H. Steier, *Topical Meeting on Organic Thin Films for Photonic Applications*. Long Beach, CA, Oct. 1997
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16. "Modified attenuated total reflection for the fast and routine electrooptic measurements of nonlinear optical polymer thin films" A. Chen, V. Chuyanov, S. Garner, W. H. Steier, L. R. Dalton, *Topical Meeting on Organic Thin Films for Photonic Applications*. Long Beach, CA, Oct. 1997.
17. "In situ trimming of polymer optical waveguides by rapid photobleaching for tuning device specifications" A. Chen, F. I. Marti-Carrera, V. Chuyanov, S. Garner, S. S. Mao, Y. Ra, L. R. Dalton, *Topical Meeting on Organic Thin Films for Photonic Applications*. Long Beach, CA, Oct. 1997.
18. "Vertical tapered mode size transformer in polymer waveguides for efficient fiber coupling", A. Chen, V. Chuyanov, F. I. Marti-Carrera, S. Garner, W. H. Steier, J. Chen, S. Sun, Y. Ra, S. S. Mao, L. R. Dalton, *Topical Meeting on Organic Thin Films for Photonic Applications*. Long Beach, CA, Oct. 1997
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21. "Mode transformer with a taper section in polymer waveguide devices for efficient fiber coupling" A. S. Chen, V. Chuyanov, F. I. Marti-Carrera, S. Garner, W. H. Steier, J. Wang, S. Sun, L. R. Dalton, *SPIE Photonics West*, paper 3005-11, Febr. 1997

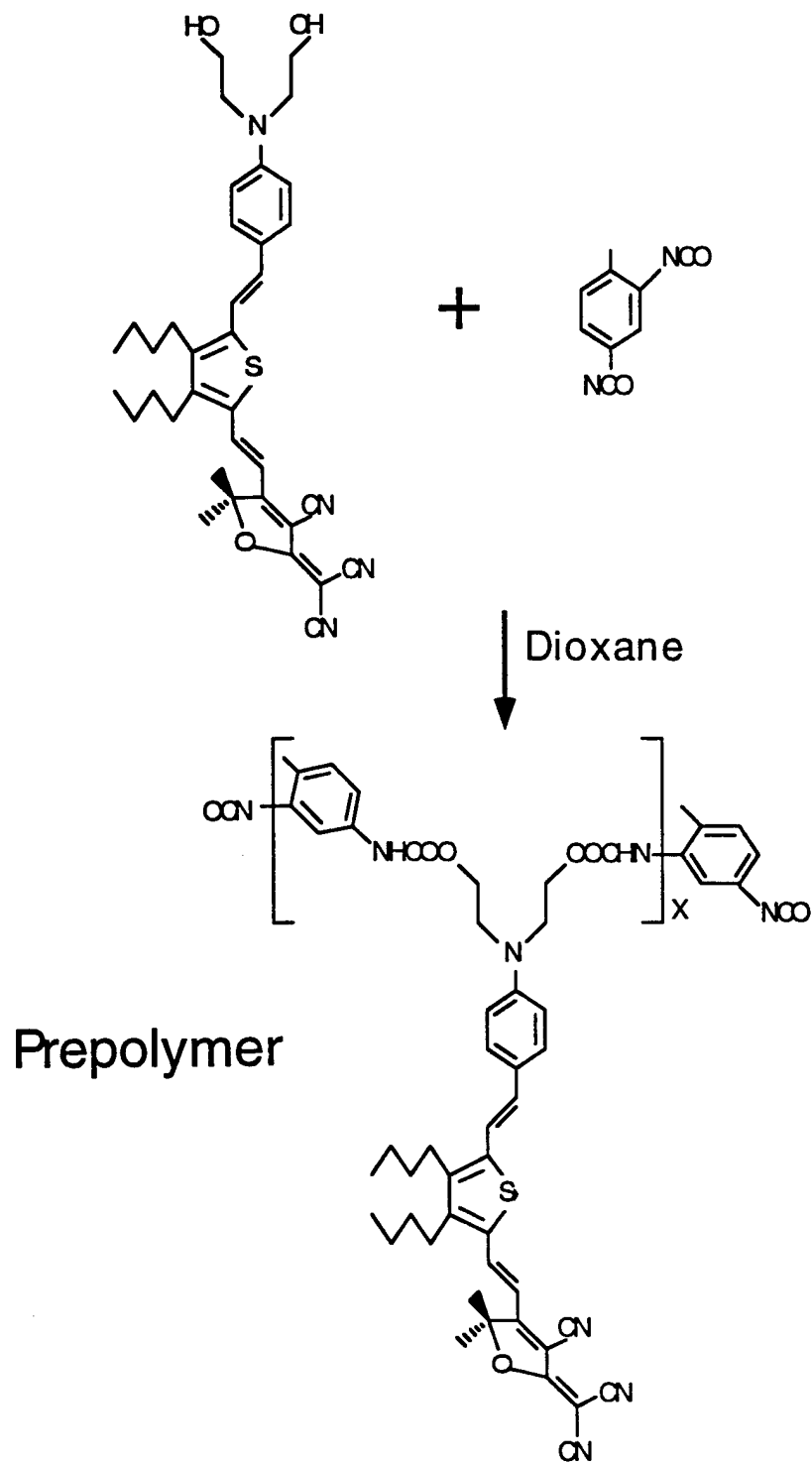


Fig. 1 The electro-optic polymer TSPU-FTC

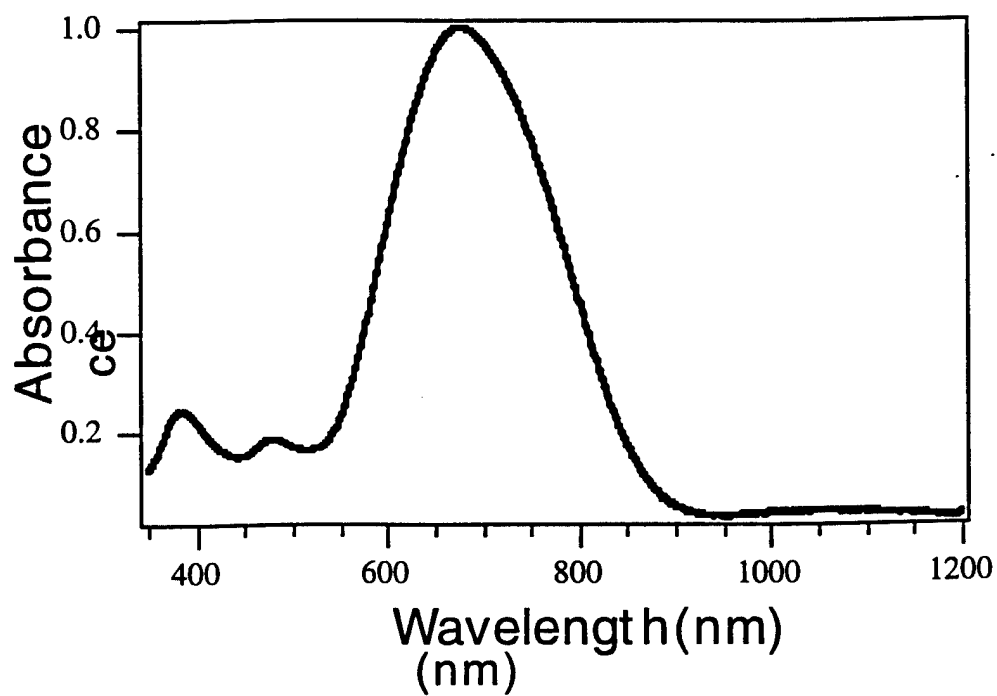


Figure 2 Absorption spectra of FTC chromophore in thermal-set poly-urethane

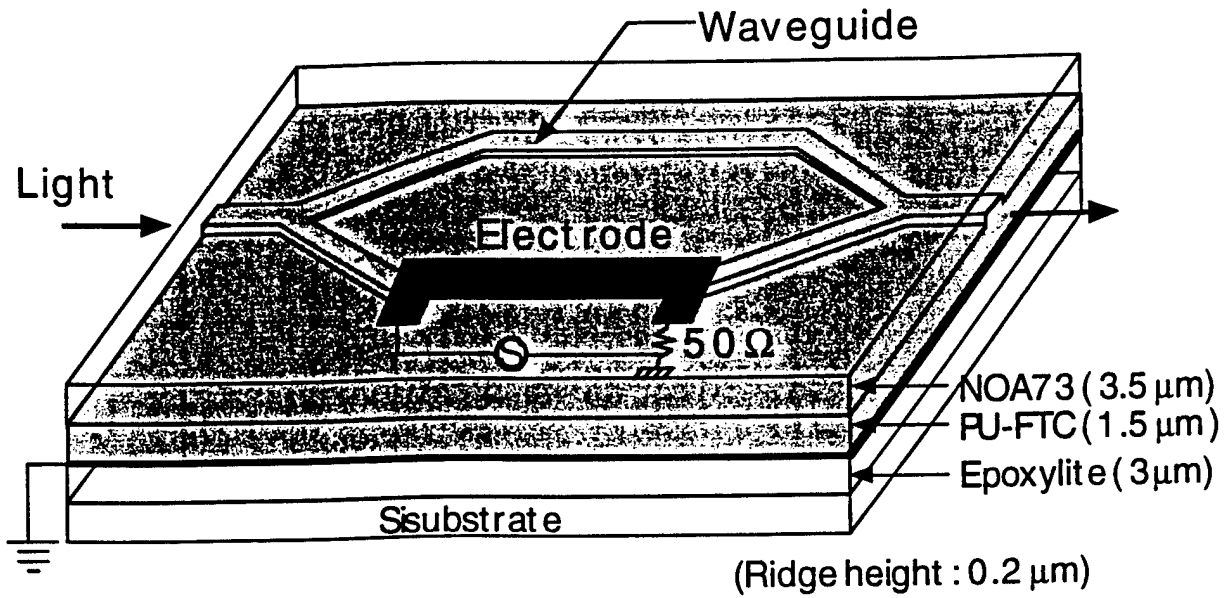


Figure 3A. Mach Zehnder infrared modulator

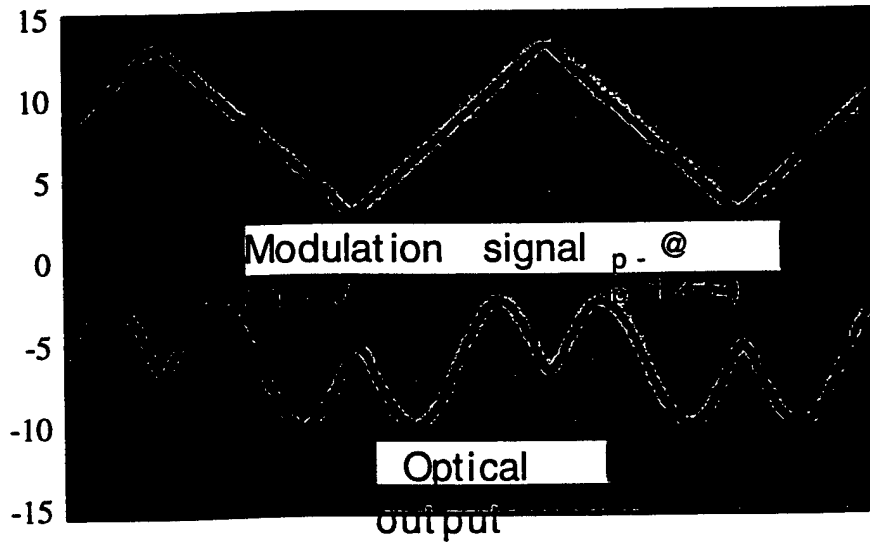


Figure 3B. Measurement of V_{π} by applying low frequency saw tooth wave form. The measured V_{π} was 4.5 V @ 1300nm.

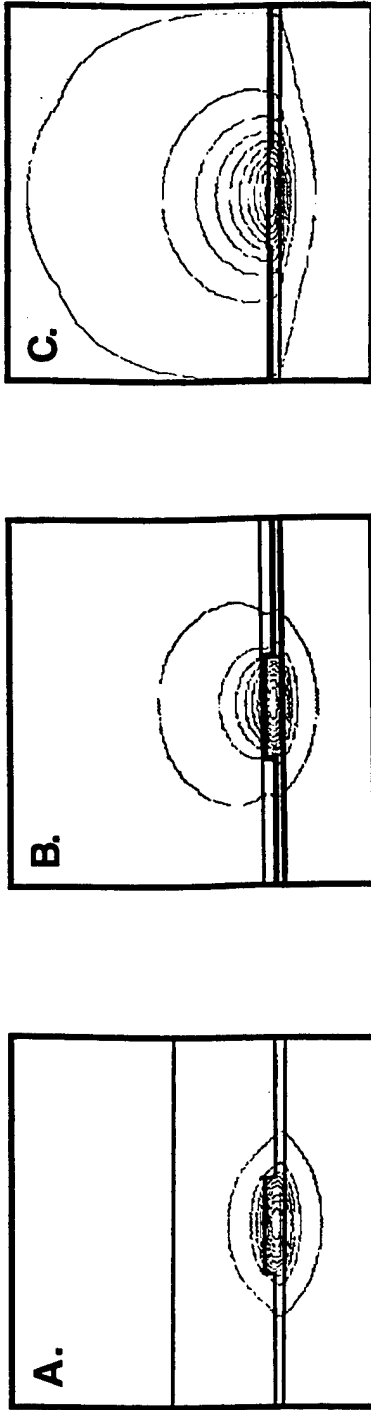
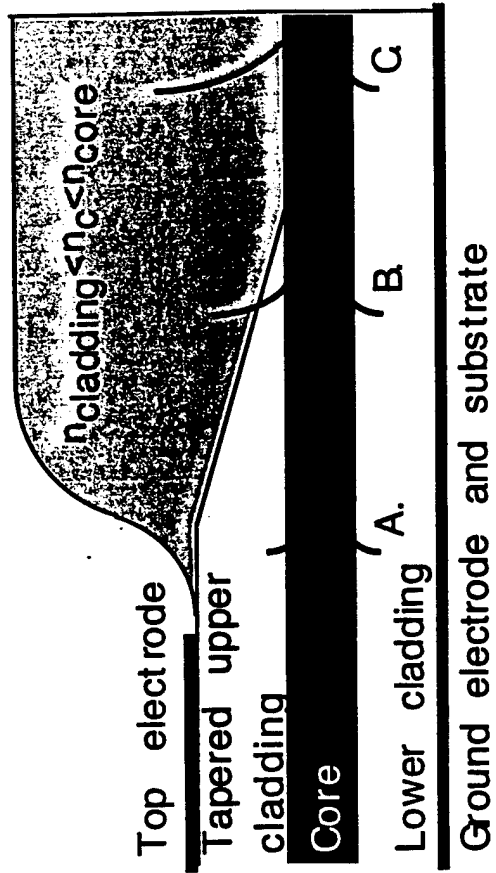
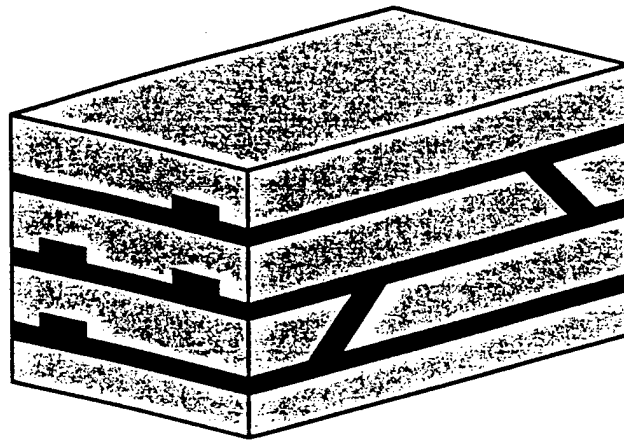
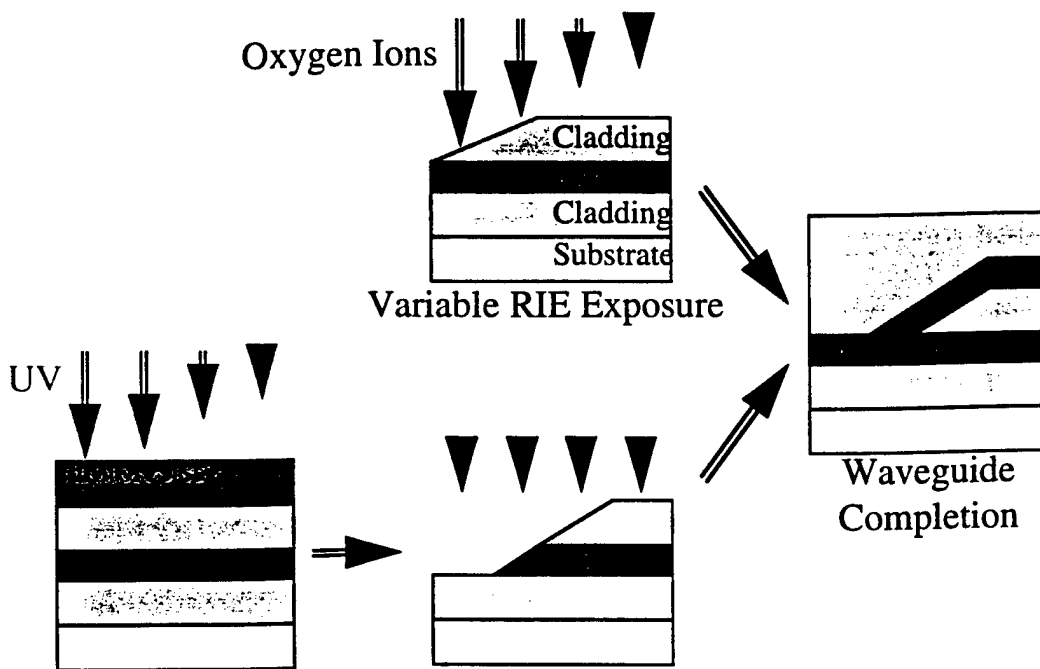


Figure 4. Schematic of mode size transformer for fiber coupling. The high index upper cladding is etched away and replaced with a lower index polymer. The mode expands upward into the upper cladding to give a larger mode diameter.



A. The concept of 3D integrated optics



B. The fabrication of vertical bends and power splitters using polymers and reactive ion etching

Figure 5. Three dimensional integrated optics in polymers

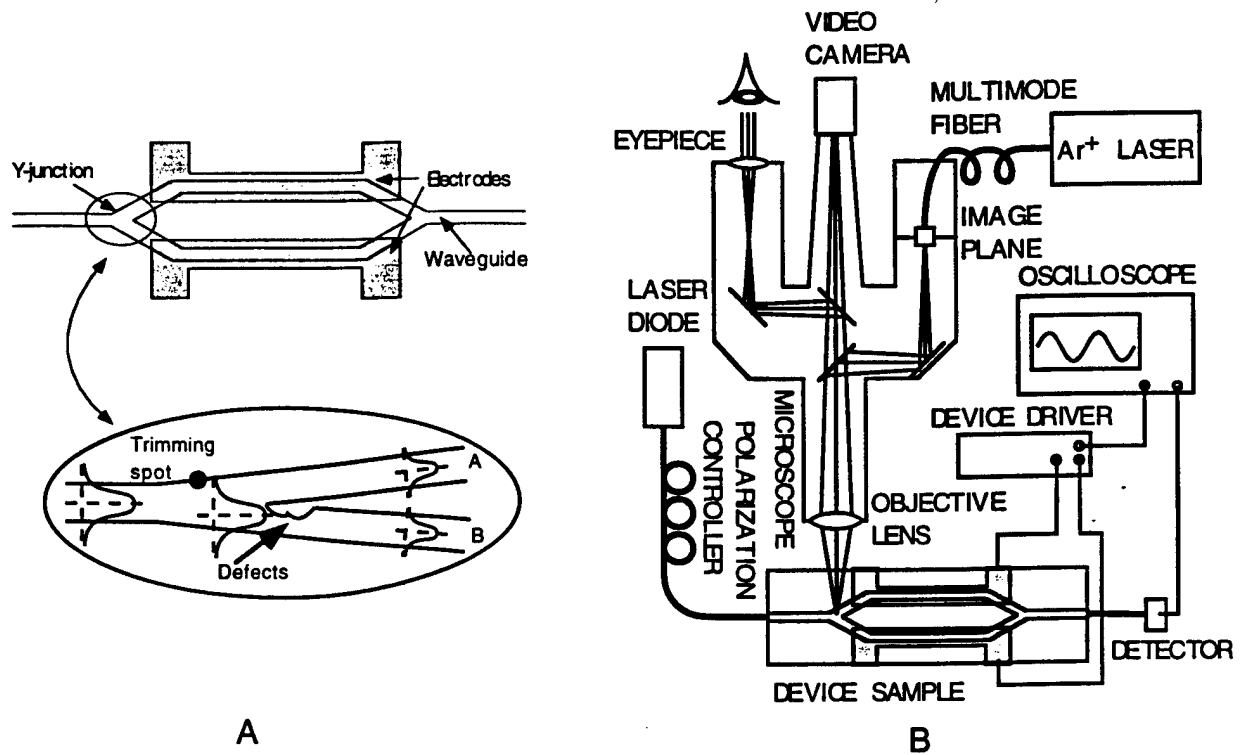


Figure 6. Trimming of the Y branch of a Mach Zehnder interferometer by photo-bleaching. A. The trimming concept. B. The trimming instrument in which the argon ion laser radiation is controlled by a microscope and video camera.