POLYMER MODULATORS WITH BANDWIDTH EXCEEDING 100 GHz

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Abstract: Ultra-high speed electro-optic modulators have been fabricated on Mylar with integrated electrode transitions for W-band(75-110 GHz) operation. New polymer systems such as APII and FTC have been developed that are low loss, stable and have electro-optic coefficients exceeding that of $LiNbO_3$.

Introduction

Recently we have fabricated and tested modulators that have worked at frequencies as high as 113 GHz [1]. These were prototype devices, based upon the polymer DR19 and were contacted using high frequency coplanar probes. In this paper we have extended these measurements to integrated optical modulators which directly couple to W-band waveguide. Further, we have fabricated these devices from a new class of Chromophores that have been designed to have a shape that reduces dipole-dipole pairing. This leads to structures that have large loading densities and relatively high electro-optic coefficients. In particular, this paper reports initial results with APII and FTC materials.

Polymer Modulators with Integrated Finline transitions

Efficient coupling of W-band microwaves into the microstrip line of the polymer modulator necessitates the design of integrated transition structures at these frequencies. In this paper, we present a set of new devices with monolithically integrated anti-podal fin-line transition [2]. This transition gradually transforms the electric field profile of the rectangular metallic waveguide to that of the microstrip line electrode on the device and effectively couples the microwave driving power into the modulator.

In going to high frequencies, which must connect to waveguide, silicon substrates cannot be used because of their high microwave losses. Instead, we have used mylar substrates, which are inserted directly into the microwave guides with fin-line transitions. A photograph of the fabricated device is shown in Fig. 1a. Note that it is very straightforward to make arrays of modulators with polymer materials. The packaged device is shown in Fig. 1b.

Fig. 1(a): W-band Modulator on Mylar

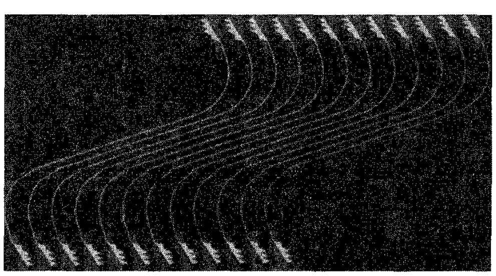
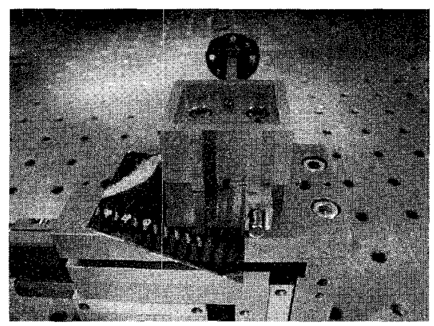
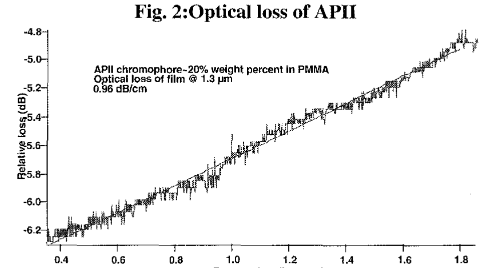


Fig. 1(b): Photograph of the device after insertion of the finline transition into the rectangular waveguide



S-parameter measurements on the microstrip line with the fin-line transition showed very good transmission characteristics with a maximum loss of 8 dB over the entire frequency band with each transition contributing a loss of 3 dB. The fin-line transition is an efficient scheme to launch microwave power from rectangular waveguide into the microstrip line and is a viable option for packaging polymer modulators at very high frequencies.

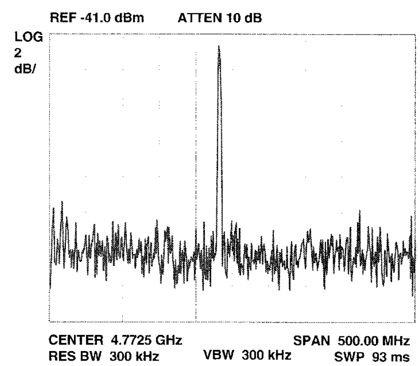
Fig. 2:Optical loss of APII



Recent efforts in non-linear organic chemistry have resulted in the synthesis of polymers with electro-optic coefficients close to or even exceeding that of $LiNbO_3$. One such polymer developed by Dalton *et. al.* is Amino Phenylene Isophorone Isoxazolone (APII) which has a $r_{33} = 26$ pm/V at an optical wavelength of 1300 nm [3]. APII also exhibits low optical losses and high stability. The optical loss of the APII as a function of the propagating distance is shown in Fig. 2. As can be seen, the losses are about 1dB/cm and are only slightly higher in going from 1.3 to 1.5 μm. These systems are also very robust and we have used them with fairly high power levels (>20 mW). This has permitted us to make several new types of opto-electronic oscillators working at high frequencies and having excellent frequency stability. The integrated devices described in this paper were made using APII, which is the first of the next generation polymers we have used.

The W-band response of the integrated modulator was measured using an optical heterodyne detection system [4]. A Gunn diode was used as the 95 GHz microwave driving source and light from a diode pumped Nd:YaG laser was butt coupled into the optical waveguide of the device. The modulation frequency incident on the photodetector was downconverted to the IF by optically heterodyning with a semiconductor laser tuned around 90 GHz from the Nd:YaG laser. The typical response of this system at high frequency is shown in Fig. 3. The excellent microwave performance of the integrated transition signals the first successful efforts in packaging of polymer modulators at such high frequencies.

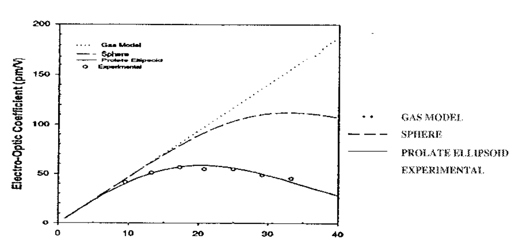
Fig. 3: Modulation signal of the APII phase modulator at 95 GHz down-converted to IF of 4.77GHz



Evaluation of Modulators made using the polymer FTC

Another polymer, which has shown to be even more attractive than APII at infrared wavelengths, is Furan Tetracyano Indane (FTC). Measurements made on this material exhibited an electro-optic coefficient r_{33} = 55 pm/V and optical waveguide losses of only 0.7 dB/cm.. The dependance of r_{33} on the loading density and the shape of the chromophore is shown in Fig. 4. Much higher values of r_{33} can be achieved by carefully tailoring the shape of the Chromophore to that of a sphere, thereby reducing the dipole-dipole repulsive interactions.

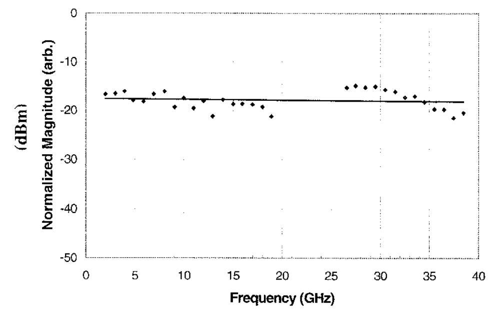
Fig. 4: Effect of chromophore shape on the r_{33} of FTC in a PMMA Host



Number Density ($10^{19}/cm^3$)

Using this polymer, we have fabricated a set of Mach-Zehnder and phase modulator devices on silicon substrates. The V_π of the Mach-Zehnder modulators was measured to be 8 Volts. The frequency response of these devices was measured from DC to 40 GHz as shown in Fig. 5. These devices show excellent performance with almost no roll-off to 40 GHz. The ripple in the frequency response was attributed to a resonance in the microstrip structure. We have recently fabricated another set of FTC Mach-Zehnder modulators that have a V_π = 4.5 V which corresponds to a V_π = 2.25 Volts in a Push-Pull configuration.

Fig. 5: Frequency response curve for FTC modulator to 40 GHz



In conclusion, the low values of V_π combined with the ease of fabrication and packaging makes this new generation of polymer modulators strong candidates in commercial communication and military applications. In addition, the excellent microwave performance of the integrated devices at W-band frequencies takes us a step closer in realising the promise shown by polymer systems for superior performance over $LiNbO_3$ at ultra-high frequencies.

References

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