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ABSTRACT

We propose a new electrooptic antenna design using organic polymer to receive microwave signals. In this paper we present the characterization of an electrooptic organic polymer. We measured the dielectric constant at microwave frequencies, and the electrooptic coefficient. We measured values of r_{33} of 3.35 pm/V at 1310 nm and 1.98 pm/V at 1550 nm. The goal of the electrooptic antenna design is to obtain maximum microwave and optical interaction. We propose a novel approach based on resonance effect in both optical and microwave domain. For the optical resonance effect we use a Fabry-Pérot cavity, and a patch structure as microwave resonator.

Keywords: Electrooptic, organic polymer, characterization, antenna

1. INTRODUCTION

Fiber optic is well suited to transmit high bit rate between country long hall or between two cities medium hall, but fiber optic is an expensive channel to connect every building, as fiber to the home (FTTH). Microwave communications, through LMDS channel, is a relevant approach to transmit data to the home. Optoelectronic transmitters are expensive to produce and present high electrical power consumption, we propose a new approach based on a low cost polymer electro-optic antenna, as shown on figure 1, to receive radiofrequency signal in the 0.1 - 30 GHz range. Here the operating frequency is 6.3 GHz to meet Wi-Fi requirements.

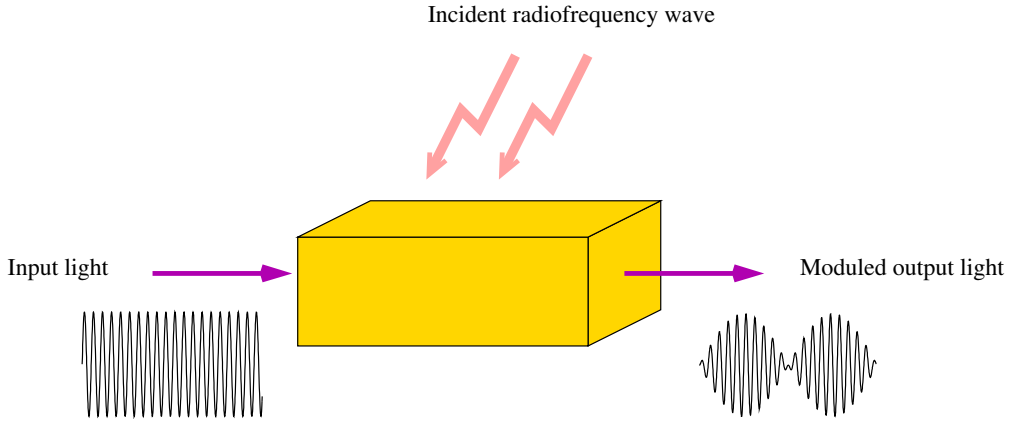

Figure 1. Electrooptic antenna

The trend on home connexions is to use increasing frequencies. Thus the purpose of the device is to enhance sensitivity by using resonant phenomena both in microwave and optical domain. Our current researches focus on the receiving part of the antenna, the microwave to optical part, where the user sends the signal to our optoelectronical transmitter. The purpose

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is then to receive the information carried out on microwave signal, and to transmit directly to optical one. The free space radiofrequency signal is captured and condensed inside the device.

The latter uses the Pockels effect in materials : the electrically-induced index modulation. The optical index's change modifies the propagating optical waves speed, then results in a variation of the polarization. The polarization modulation can be converted in amplitude modulation by using polarizer or other means.

Two electrooptic-enabled materials are under interest. The older one is lithium niobate, which presents high electrooptic coefficient (35 pm/V at 1550 nm), but high dielectric constants ($\varepsilon_r \approx 43$ and 28) and index ($n \approx 2.2$), and has a high production cost. Nevertheless electrooptical modulator with lithium niobate have been proven to work up to 40 GHz. By the way, the bandwidth of this kind of modulator is limited due to the high velocity mismatch between optical and radiofrequency waves.

Poled polymers are promising electrooptical material. The low permittivity ($\varepsilon_r \approx 3$) and optical index ($n \approx 1.6$) reduce the velocity mismatch inside the material, thus providing a bandwidth up to 102 GHz.[1,2] Whereas actually electrooptical polymer properties and stability are lower than lithium niobate ones, the gap between those technologies is decreasing. The first polymer we use in this work is a PGMA backbone, associated with a DR1 side chain chromophore with epoxide cross-linkable function.[3] This polymer has the advantage to combinate the well-known PGMA/DR1 electrooptic properties with long-term stability provided by cross-linking.

The optimal size of the device depends mainly on the electrooptic and dielectric polymer's properties. In the following, we will present the electrooptic and micro-wave frequencies characterizations of the material, and an overview of the probe design.

2. ELECTROOPTICAL CHARACTERIZATION

Since poled polymer films have uniaxial anisotropy, and by symetry considerations, we need to know only the r_{31} and r_{33} elements of the electrooptical tensor.[1] We use a reflexion technique, first proposed by Teng and Man.[4] The goal of this free-space method, presented figure 2, is to provide an estimation of the final electrooptic coefficient. Among other assumptions, this technique states that $r_{33} = 3r_{31}$ and there are no other reflexion than the one at the top electrode. By the way it has been shown that the factor would be between 3 and 6 rather than 3.[1]

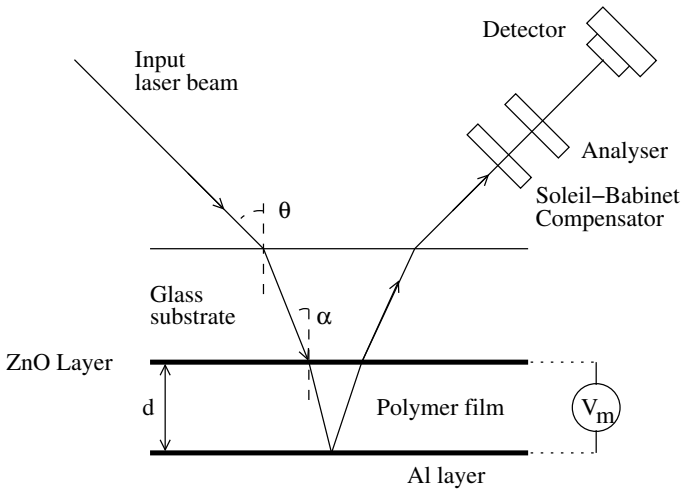


Figure 2. Teng and Man principle

In this experiment, we measure the modulated portion of the detected optical signal I_m, and I_{max} the intensity just before the analyser. Knowing the modulation voltage V_m, the polymer optical index n, the incidence angle θ and the wavelength λ, we obtain the electrooptic coefficient r_{33} :

$$r_{33} = \frac{3\lambda}{2\pi V_m} \frac{\sqrt{n^2 - \sin^2\theta}}{n^2 \sin^2\theta} \frac{I_m}{I_{max}} \tag{1}$$

2.1. Samples preparation

A glass subtrate was first coated with 1-μm-thick ZnO as bottom electrode. Then the polymer, a crosslinkablee PGMA/DR1 side-chain system, dissolved in (1,1,2-Trichloroethane) was spun-cast on the ZnO. The samples were then poled by corona effect, by applying 5 kV over 1 cm between the pin and the ground electrode and warming the sample up to the glass transition temperature and then cross-linking temperature. Thereafter, the top aluminium electrode was evaporated. The layer superposition is shown figure 3.

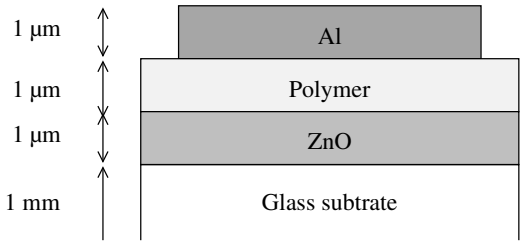


Figure 3. Sample cut. Polymer is deposited over ZnO glass subrate. An Al electrode is evaporated onto the polymer layer.

2.2. Experimental setup

The electrooptic coefficient characterization setup we used is presented Fig. 4. First, laser beam goes throught a fiber optic an a fiber collimator. Two IR wavelength can be selected using this fiber : 1310 nm and 1550 nm. After the collimator, the laser beam propagates in free space. A polariser, sets the laser beam polarization at +45° of sample's axis. The Soleil-Babinet-Bravais compensator cancels the static relative phase retardation caused by the polymer anisotropy.

Then the beam goes through the sample, reflects over the aluminium top electrode. The analyzer, set in quadrature of the polarizer, changes the polarization modulation in intensity modulation. The photodetector, a PDA400 from Thorlabs, is used to convert the optical modulation in a electric modulation. The detected signal is measured by a voltmeter to get the continuous component of the signal, and a lock-in amplifier to measure the modulated part. An oscilloscope simplifies the sample alignment and displays the modulating voltage.

During the measurement, the minimum and maximum signal intensities are measured using the Soleil-Babinet compensator. Then the compensator is then configured at half-intensity $I_c = (I_{cmax} + I_{cmin})/2$. Then the modulation intensity is measured for half-intensity I_c at both sides of maximum or minimum intensity by moving the compensator. The average modulation intensity $I_m = (I_{m1} + I_{m2})/2$ is then used in (1), with $I_{max} = (I_{max} - I_{min})/2$, and V_m measured with the oscilloscope.

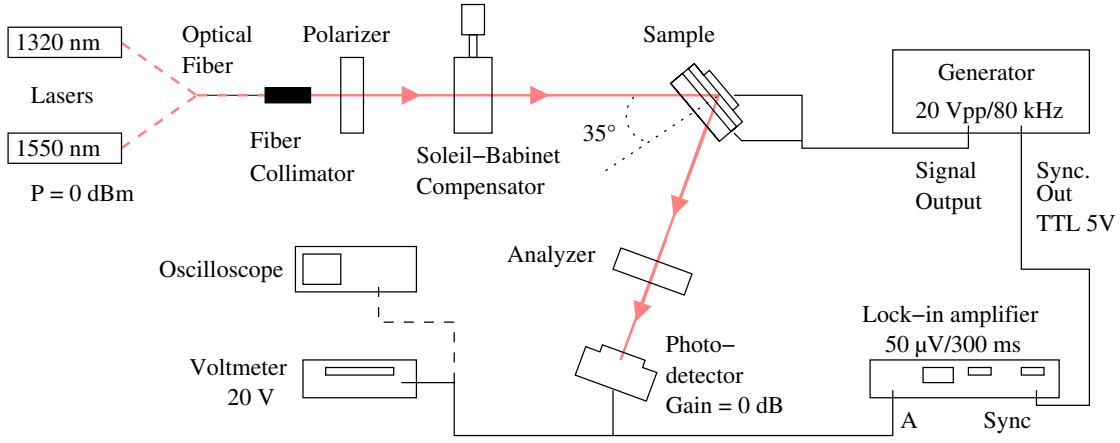


Figure 4. Teng and Man experimental setup as implemented in IREENA labs.

2.3. Results

The measurement results over 4 samples are reported in Fig. 5. The incidence angle is 35°, where the detected signal amplitude is maximum. We used a laser optical power of 1 mW, thus the signal amplitude detected with the lock in amplifier was in the 0 - 50 μV range.

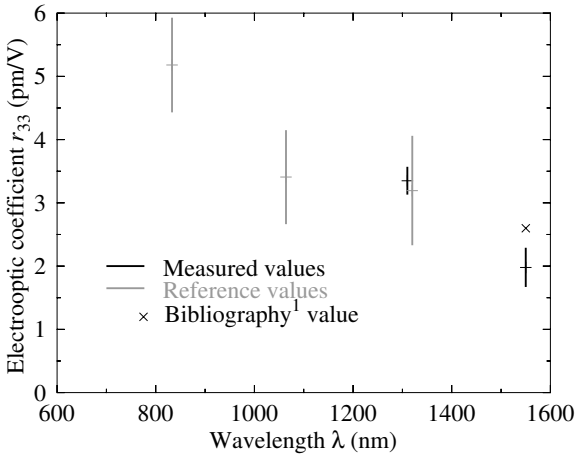


Figure 5. Electrooptic coefficient measurement results.

2.4. Analysis

The values of electrooptic coefficient are lower than the 10 pm/V expected : we measured values around 3.2 pm/V at 1320 nm. For reference we reported the electrootpic coefficient values measured using the same samples at Thales Research & Technology (TRT), Orsay, France. At the common wavelength, 1310 nm, values are in good agreement. Since there was 8 months between the two measurements, we can conclude the polymer stability is good over time.

We also compared those results to litterature,[1] where the polymer, the sample preparation and the measurement technique are quite similar : a sidechain PMMA/DR1 polymer, poled using the corona method and measured using through-plane method. Our measurement is in good agreement with the reported value of 2.6 pm/V at 1550 nm.

3. MICROWAVE CHARACTERIZATION

The purpose of the microwave characterization is to know the value of the relative dielectric constant of electrooptics polymers. However, this kind of material can be only deposited in thin layer in the range of 1 to 5 μm. Above this range, we have to face with fissures appearing at drying phase.

To solve this problem, we use a two-steps method to get the relative dielectric constant. First we determine an approximation of the low frequency dielectric constant, and this value is then used to size an high-frequency characterization structure.

3.1. Low frequency estimation

A simple permittivity measurement method for thin film is a capacitance method. It involves the measurement of three parameters. Indeed, the dielectric constant ε_r is related to the surface S the thickness d and the capacity C by :

$$C = \varepsilon_0 \varepsilon_r \frac{S}{d} \tag{2}$$

Where ε_0 is the free space dielectric constant. We then have to mesure the capacity C, the surface S and the thickness d to quickly obtain the low frequency dielectric constant.

3.2. Sample preparation

The polymer is deposited on an aluminium layer over a glass substrate using spin coating at 4000 rpm during 30 seconds. Then 16 2-mm diameter aluminium electrodes are evaporated on the sample's polymer layer. For each small condensator we measured the capacitance at 1 MHz using an impedance/gain-phase HP4149A. The capacity measurement error is 4 % in the worst case. For thickness measurement, we use a destructive method. We cut other samples deposited using same parameters, and measure the thickness with SEM photography. The precision is $\pm$ 50 nm.

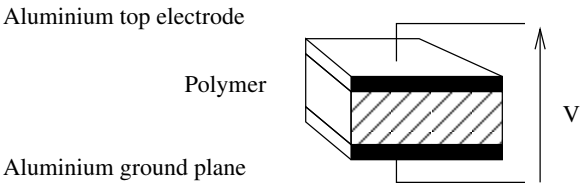


Figure 6. Low frequency capacity measurement principle

3.3. Results

As experience validation, we measured the dielectric constant of PMMA layers. There was 4 samples of 16 condensators, meaning 64 capacity measurements. Those measurements are presented Tab. 1. The evaluated thickness is 970 $\pm$ 50 nm. We reported table 1 the permittivity computed using this value. Therefore, the average permittivity is ε_r = 2.79 $\pm$ 0.15. This value agrees with litterature's value of 2.6.[5]

Sample	Mean capacity	Permittivity
1	77.22 $\pm$ 0.55 pF	2.71 $\pm$ 0.17
2	85.63 $\pm$ 1.12 pF	2.99 $\pm$ 0.20
3	77.21 $\pm$ 3.21 pF	2.69 $\pm$ 0.26
4	79.46 $\pm$ 2.12 pF	2.77 $\pm$ 0.22

Table 1. Mean capacity and per-sample estimated permittivity for each sample, using 970 $\pm$ 50 nm for thickness.

3.4. Microwave permittivity measurement

Since we will use our electrooptic antenna at discrete microwave frequencies, we can focus on resonant characterization methods, to get the dielectric constant only for working frequencies.

A simple microwave resonant structure is a patch resonator. Its resonant frequency is given by[6] :

$$f_{mn} = \frac{c}{2\pi\sqrt{\varepsilon_r}} \cdot \sqrt{\left(\frac{m\pi}{L_{eff}}\right)^2 + \left(\frac{n\pi}{W_{eff}}\right)^2} \tag{3}$$

With L_{eff} the electric length given by $L_{eff} = L + \Delta L$, where ΔL is :

$$\Delta L = 0.412d\frac{(\varepsilon_{eff} + 0.3)\left(\frac{L}{d} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{L}{d} + 0.813\right)} \tag{4}$$

and ε_{eff} the effective permittivity :

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \sqrt{1 + 10\frac{d}{L}} \tag{5}$$

The replacement of L by W in the previous equations gives W_{eff}. Unlike the capacitor method, the thickness is not really needed for thin films : when d goes to 0 in (4), ΔL tends to be 0. Then, to know the diectric constant, we only have to measure the first resonant frequency of the structure with a VNA, and using the length and the width of the patch, we can retrieve the microwave permittivity.

3.5. Sample preparation

The samples are made through the same process as the capacitors, but there is only one rectangular shaped top electrode.

The main drawback of the method is the way to put microwave energy in the structure : we cannot put a SMA connector directly onto the patch. We then use a 1 cm long microstrip line as an interface between the VNA and the patch. We solder a SMA connector to the VNA side of the line, and for the patch side, we solder a short thin wire. The wire's other end is connected to the patch using metallised paint. The patch groundplane is linked to the microstrip line groundplane by the same way. A prepared PMMA/DR1 sample is shown on photograph figure 7.

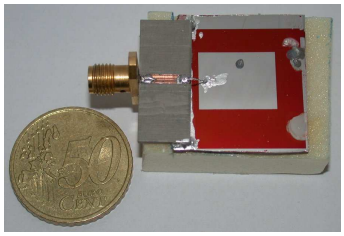


Figure 7. Picture of a PMMA/DR1 sample with Al evaporated top electrode. Electrode is 15 mm wide, 12 mm long.

3.6. Results

Before applying this method on polymers substrates, we first tested it on thick substrates, $i.e.$ we would like to prove the validity and to study the thin wire influence.

We measured the reflexion coefficient for two substrates : Rogers RT/Duroïd 6006 and Teflon glass (Fig 8). The reference plane used for calibration is the end of the microstrip line. Unlike the thin film case, here we have to take the substrate thickness in account. The measured frequency and the permittivities deduced from those measurement are shown Tab. 2.

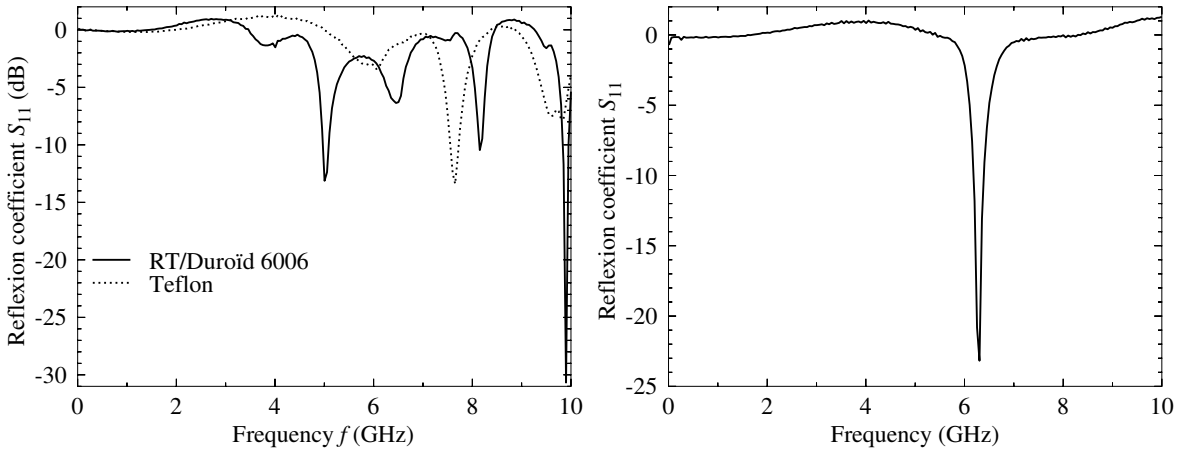
Substrate	Measured frequency	Permittivity
Thick substrates		
Teflon glass 0.6 mm thick	7.654 GHz	2.54 ± 0.02
Rogers RT/Duroïd 6006 1.27 mm thick	5.043 GHz	5.62 ± 0.07
Thin subtrate		
PMMA-DR1	6.30 GHz	2.52 ± 0.5

Table 2. Measured frequencies and deduced dielectric constants for two thick substrates. Frequency values given at $\pm$ 30 MHz for thick subtrate and $\pm$ 50 MHz for thin subtrate.

For the teflon glass, measurement is in good agreement with constructor provided values of 2.55 ± 0.15. Whereas the measurement for the Rogers RT/Duroïd 6006 differs of 8% to 6.15, given by Rogers Corp. Thoses results show that this method can be used for material characterization. As first thin-layer experiment, we use the PMMA-DR1 sample shown on photogragh Fig. 7. The measured frequency, reported in Tab. 2, is GHz and 6.30 ± 50 MHz. The deduced permittivity is then between 2.52 ± 0.5. This value differs from 16% with the value of 3.01 found in litterature.[7] This result should be take carefully, as it is our first measurement using this method. We are currently working on the result accuracy improvement, by lowering the frequency measurement error.

4. THE ELECTROOPTIC ANTENNA

A metallic rectangular shape over a metallic substrate is a conformal patch antenna. Then the Teng and Man experimentation samples are a kind of first electrooptic antenna. At resonant frequency, the patch structure concentrates the electric field between the top electrode and the ground plane. The concentration may be as high as 1000:1, meaning 1 V/m amplitude incident wave generates 1 kV/m inside the structure. The choice we made here is then to reduce the device bandwith and then increasing the sensistivity inside the bandwith.



(a) Rogers RT/Duroïd 6006 and Teflon glass subtrates

(b) PMMA-DR1 based substrate

Figure 8. Reflexion coefficient measurement for two substrates thickness : mm-thickness as Teflon glass and RT/Duroïd 6006, μm-thickness as PMMA/DR1.

Since the coating method and the synthetized polymer volume both limit the thickness of our samples, to enhance the performances, the idea is to increase interaction between the microwave signal and the optical beam inside the structure. The optical path length can be increased using Fabry-Perot effect inside the structure.[8] The total optical path length vary with cavity finesse, but we expect a ratio from 10 to 100 compared to a single reflexion structure.

Using this novel approach, combining microwave and optical resonant structures, we expected a overall sensitivity ratio of 10000:1 comparted to the non optimized case.

We are currently working on a quantification of this novel approach. Later, the antenna would be pigtailed to build an high-sensitivity electrooptic E-field sensor.[9]

5. CONCLUSION

In this paper we focused on the characterization of organic polymer. We measured values up to 3.35 pm/V at 1310 nm and 1.98 pm/V at 1550 nm for optical coefficient of crosslinkable PGMA/DR1 polymer and proved the stability of the material over 8 months. We also presented two dielectric constant measurement methods. The low frequency capacity-based permittivity measurement was demonstrated using a PMMA polymer and a value of 2.79 ± 0.15 was found in good agreement with litterature. We achieved microwave permittivity measurement using a resonant patch method. The result of 2.52 ± 0.5 for PMMA/DR1 is in the order of magnitude of litterature's values.

Our future work will concern the enhancement of the electrooptic antenna, using a Fabry-Perot cavity in optical domain and a patch antenna in microwave domain to incresase the sensitivity of the antenna.

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