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Experimental comparison between corona and contact poling for EO polymer modulators

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Abstract: Two different poling techniques—corona poling and contact poling in the backdrop of electro-optic (EO) polymer modulators are compared. A 3-layer structure EO polymer modulator is prepared for the poling. The poling setups and procedures of these two different methods are given. It is found that a well-controlled pre-cure step is very critical, otherwise it will result in either lower poling efficiency or damaged film. Experimental results show that contact poling does not create severe surface damage as corona poling and poling voltage is much lower, but corona poling provides higher EO effect than contact poling. Besides, contact poling can provide poling size as large as the substrate size.

Key words: corona poling; contact poling; electro-optic polymer; modulator

As one of the fundamental building blocks of optical communication or interconnect systems, modulators have attracted tremendous academic research and industrial development resources and will continue to be in the focus of such effort for many years to come. The external modulators are the prime choice of high speed systems thanks to their excellent characteristics such as lower chirp noise and higher modulation speed, to name just two[1,2], compared to direct modulators.

EO modulators made from inorganic material, such as lithium niobate ($LiNbO_3$), have been mature product options and used for quite a long time[3]. However, their drawbacks are equally well known. Fortunately polymer offers the ability to overcome some of the drawbacks of the inorganic crystals and silica-on-silicon technology because it can be spin-coated and processed using very large scale integration (VLSI) fabrication techniques. Thus polymer modulators can be easily integrated onto a chip with lasers and detectors. Polymer also offers the advantage of lower operational voltages; thus lower power consumption and better high speed performance as a result of its thinner design and lower dielectric susceptibility are respectively achieved. In particular, nonlinear optical polymeric materials are one of potential options with great promises. Many exciting and promising results are presented in Refs. [4 – 6].

Poling is the primary technique to increase the electro-optic coefficient of the chemically engineered molecule structure, which can successfully provide four or five times greater EO efficiency than lithium niobate[7 – 9]. In this paper we present our experimental results regarding two different poling techniques in the backdrop of EO polymer modulators.

1 Experiments

The EO effect in polymer originating from the alignment of chromophores causes the non-central symmetry. This kind of angular alignment of chromophores can be induced by the electrical poling process. This method was first reported on polymeric system over twenty years ago[10]. There are mainly two types of poling techniques perfected through years of practice: corona poling and contact poling.

1.1 Preparation

Before poling, candidate films need to be prepared on a 3-layer structure beginning with the bottom electrode, the bottom cladding and the core. The first layer was an e-beam evaporated double-metal layer on the silicon wafer serving as poling bottom electrodes. The electrode consisted of 15 nm chromium covered by a layer of 200 nm gold. The chromium was used as an adhesion layer. A solution for the bottom-cladding layer consisting of norland optical adhesive-61 (NOA-61) was prepared by mixing 1 mL NOA-61 with 3 mL solvent cyclopentanone and stirred for 5 min. The solution

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was drawn into a syringe and partially cured with UV light at an intensity of about 16 to 20 mW/cm^2 from a UVP ultraviolet lamp for 3 min. Next, the bottom-cladding solution was dispensed from the syringe onto a silicon wafer using a 0.2 μm filter, then spin-coated on Au film and fully cured for 20 min by UV light. The last coating on substrate was the core layer. We dissolved 0.2 g DR1 (provided by IBM) in 1 mL cyclopentanone and filtered it with a 0.2 μm syringe filter, and spin-coated onto the NOA-61 layer and dried in vacuum to remove the solvent. This resulted in a core layer with a thickness of about 5 μm.

1.2 Corona poling

The schematic diagram of the corona poling setup is shown in Fig. 1. To achieve the best EO coefficient without damaging the polymer surface (a common phenomenon), different poling conditions such as curing temperature, time and pre-cure processes were investigated extensively in advance as part of our study. The poling profile consisted of two major steps: pre-curing and electrical poling, as shown in Fig. 2. The optimal conditions in our experiments are as follows: needle-to-plane distance is 2 cm, high voltage is 8 kV, pre-curing heating time is 3 min at 120 ℃ and poling time is 60 min at 110 ℃.

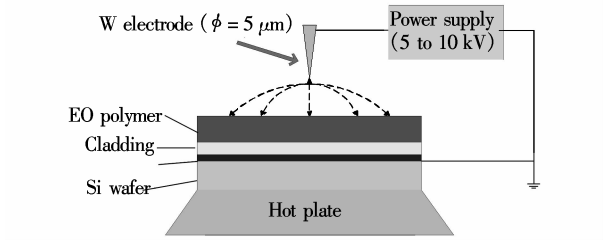


Fig. 1 Schematic diagram of the corona poling setup

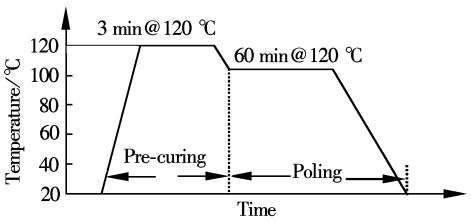


Fig. 2 Poling profile for corona poling

Experiments confirmed that a well-controlled pre-cure step was very critical to avoid poor poling efficiency or damaged film. There was a tradeoff between the pre-curing and the poling efficiency. If the pre-curing was not sufficient, it was easy to get high efficiency but surface damage easily occurred as well; if the pre-curing was excessive, the rotation of the chromophores was restricted and the poling efficiency was reduced.

It was also found that the poling temperature affected the thermal stability of the EO film. Too low poling temperature resulted in poor EO coefficient and thermal stability.

1.3 Contact poling

In contact poling, an electric field was applied to the EO polymer film by two parallel electrodes (the bottom Au serves as one of them). To obtain a good contact everywhere on the surface, a thin bottom electrode layer of Au (110 nm) was first thermally deposited on the space between the top poling electrode and the top surface of the core layer. The schematic setup is shown in Fig. 3. Hexatriacontane has a melt point at 75 ℃, which is lower than the poling temperature of EO polymers.

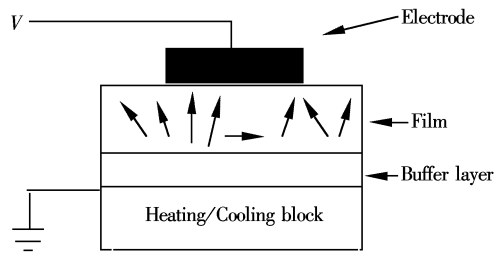


Fig. 3 Schematic setup of contact poling

The contact poling procedure consists of three steps. The first step comprised of a temperature ramp from room temperature to 80 ℃ and it was held at 80 ℃ for 10 min. This allowed the solid hexatriacontane to melt into its liquid state and to be drawn into the gap between the ITO electrode and the top surface of the polymer via the capillary force. The second step consisted of a temperature ramp from 80 ℃ to 125 ℃ within 10 min. The applied voltage started at 50 V and increased by 5 V every 5 s until it reached 900 V, just before the film's breakdown voltage by monitoring the current in the circuit, and held there for 12 min. During this step, most of the chromophores had not been crosslinked and were able to rotate to align their dipoles with the applied field. In the third step, the power to the hotplate was turned off but the high poling voltage was maintained until the temperature of the sample cooled down to about 40 ℃. An appropriate solvent, such as xylene, can remove the hexatriacontane residue.

2 Discussion

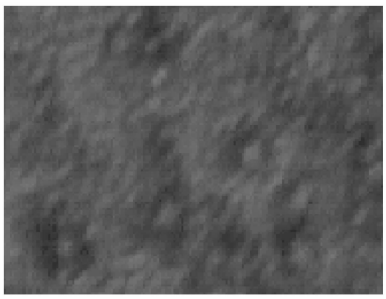
In Tab. 1, we summarized the characteristics of both poling techniques. Generally speaking, corona pol-

ing can achieve higher EO effect than contact poling. But the optical loss which is also very important in EO polymeric device is not discussed in this paper. Corona poling tends to increase the loss more than contact poling. This tradeoff decision needs to be determined by the intended application and design.

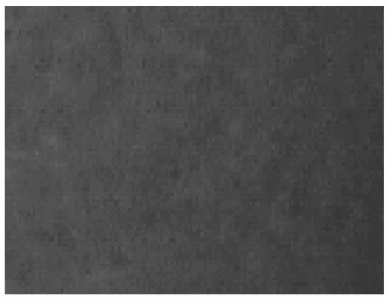
Tab. 1 Comparison of corona poling and contact poling

Poling	Poling area	Voltage	Domain-inversion	Surface quality	Complexity
Corona	Corona size	High	No	Bad	Low
Contact	Substrate size	Low	Yes	Good	High

Fig. 4 gives the morphographies of corona poled film and contact poled film. It is obvious that contact poling provides better surface quality than corona poling. A high electric field is produced by the charge deposited on the film surface through the corona discharge process. Surface damages were attributed to the strong compressive electrostatic force of the charges accumulated on the film, since the charged particles may carry large kinetic energy when they pass through the high electric potential between the corona needle and the ground electrode.



(a)



(b)

Fig. 4 Morphography of poling films. (a) Corona poled film; (b) Contact poled film

3 Conclusion

The pre-curing step is to initiate partial crosslink prior to applying high voltage. Proper pre-curing can mitigate surface damage. However, for the thermosetting material, lattice hardening is taking place during poling and can reduce the poling efficiency by preventing some of the chromophore from reorienting under the influence of the poling field.

Contact poling does not create severe surface damage as corona poling but it frequently generates localized destructive pinhole defects. So impurities and defects in the samples will result in short circuits and destroy the samples during the contact poling. For this reason, we have to be very vigilant about defects introduced in the fabrication of devices.

Contact poling in most cases can only be performed at a field much lower than the dielectric breakdown permitted by the polymer film. In this case the EO coefficient is less than what can be obtained by the corona poling method[11].

In summary, contact poling has advantages such as lower poling voltage, selective poling area and better film quality. But corona poling is easier to work with and achieves higher EO coefficient.

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电光聚合物调制器电晕极化和直接接触极化方法的实验比较

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摘要:对调制器用电光聚合物材料的2种极化工艺——直接接触极化方法和电晕极化方法进行实验比较和分析,制备了用于极化实验的3层结构的电光聚合物调制器,给出了这2种极化方法的实验装置和极化工艺. 实验发现,极化前的预处理工艺控制非常关键,否则会降低极化效率或损伤膜表面. 结果表明:直接接触极化方式对膜表面的损伤较小,极化电压低,而电晕极化方式可以得到高的电光系数. 直接接触极化方式极化的面积能够达到基板的尺寸.

关键词:电晕极化;直接接触极化;电光聚合物;调制器

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