Patterning ITO using a laser cut Kapton® tape mask for flexible PVDF applications

Kyle M. Schvaneveldt[1*], Annie Laughlin[1], Elias Guanuna[1], Keaton Shurilla[1], Luke Johnson[1], Jessica Staker[1], Quinn Hunsaker[1]and Daniel E. Smalley[1]

[1]*Electrical and Computer Engineering Department, Brigham Young University, Provo, Utah*

*Contact: kyleschvaneveldt@gmail.com, phone +1-385-482-5993

2022 IEEE International Flexible Electronics Technology Conference (IFETC) | 978-1-6654-6968-5/22/$31.00 ©2022 IEEE | DOI: 10.1109/IFETC53656.2022.9948485

Abstract— **This work describes a novel approach to patterning Indium Tin Oxide (ITO) on Polyvinylidene Fluoride (PVDF) using a laser cut Kapton® tape mask for rapid prototyping. Measurements taken before and after experimentation conclude a non-significant change in sheet resistance while using this method to pattern with a p-value of 0.2947 for a two-tailed paired t-test for significance.**

I. Introduction

PVDF is a unique material because of its high piezoelectric response [2]. Many applications of PVDF are used in a variety of industries such as the electronics industry. PVDF can achieve a high piezoelectric constant, d31, by mechanically stretching the material while inducing it into a high electric field called poling [2]. PVDF is also transparent, allowing it to be used for applications requiring a high level of transparency such as the display industry.

ITO is a conductive material that can appear transparent at small thicknesses. The use of ITO has increased over the last few decades because of this property. ITO can be deposited using multiple methods such as sputtering [1]. ITO is also flexible; however, it can exhibit noticeable increases in sheet resistance due to high amounts of stress and strain at small thicknesses [4].

Patterning of ITO has been demonstrated in multiple works with several methods [1]. The most common methods for patterning are photolithography, direct writing, and using a shadow mask during deposition [1], [4], [5]. These methods allow for mass production of patterned materials; however, pattering of ITO on PVDF poses a unique problem because the use of acetone to remove photoresist off patterned ITO can dissolve the PVDF layer underneath [3]. The use of a shadow mask is therefore optimal, but the downsides to this method are the cost, and the specialized equipment to utilize this method.

Using a Kapton® tape mask provides a means to solve the downsides of the shadow mask method. This method utilizes inexpensive materials to pattern ITO on PVDF. The ITO can be patterned rapidly using this method for quick prototyping.

II. Background

To measure the effectiveness of ITO patterning, the sheet resistance of each sample tested needed to be captured. A four-point probe from Osilla was used to capture the sheet resistance. Before etching each sample during pattering, a null hypothesis was formulated for a paired t-test. Since an optimal result after patterning the ITO would be a net change in sheet resistance of zero, the null hypothesis is that the two-population means are zero. The two populations are the before and after results.

After collecting the measurement data, a p-value can be calculated describing whether the null hypothesis can be accepted or rejected. If the p-value is greater than the level of significance of .05, then the null hypothesis can fail to be rejected.

In this work, an overlap was used to ensure that the ITO would not be removed when removing the tape. Instead of laser cutting the design out and removing all the Polyethylene Terephthalate (PET) backing that came with the Kapton® sheet, only the edges of the design had the PET removed. Exposing only the edges allows for minimal surface contact with the adhesive providing a way to preserve the sheet resistance of the ITO. The image shown in Fig. 1 is demonstrating a design used in this work during experimentation.

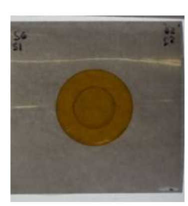

Fig. 1 Kapton® tape laser cut in the shape of a circle placed on top of a PVDF and ITO sample. The inside circle has PET and Kapton® tape whereas the outer circle is tape adhered to the ITO layer

III. Patterning Procedure

The procedure to etch ITO on PVDF using the Kapton® method is described below. A Glowforge laser cutter was used for the laser cutting portion of the below procedure.

1. CREATE a design with your desired mask with an overlap of greater than 1 mm on all sides.
2. SEND file to Glowforge.
3. SET the PET + Kapton sheet upside down or PET side up in Glowforge and tape it down.
4. DETERMINE thickness of the PET + Kapton sheet, commonly it is .1 inches thick.
5. SET the speed for cutting the inside PET mask to full speed and 40 power with 1 pass.
6. SET the speed for cutting the outside PET + Kapton mask to full speed and 90 power with 1 pass.
7. REMOVE cut mask from Glowforge and use tape or water to remove any charred areas.
8. CUT out your ITO + PVDF and tape it down to a Si wafer on all sides.
9. REMOVE the PET backing from the Kapton tape where it needs to adhere to the ITO.
10. ADHERE the KAPTON + PET mask to the ITO. It might be necessary to use transfer tape to insure precision.
11. ETCH the ITO off the PVDF in HCl for 15-45 seconds.
12. REMOVE all tape from the sample.

IV. Results

After conducting the above procedure, ten samples were made with varying overlaps between the PET backing and the adhered tape. One sample served as a control with no overlap and just adhered Kapton® tape. Measurements of the sheet resistance were taken before adhering the Kapton® mask and after etching the samples in HCl for an average of 30 seconds. Each final measurement was an average of three independent measurements taken of the sheet resistance to increase the accuracy in the results. Fig. 2 is a graph describing the sheet resistance before and after patterning.

A paired t-test for significance was run contrasting the before and after results. A p-value of 0.2947 was calculated based on the results. This value is greater than the level of significance used for the t-test of .05.

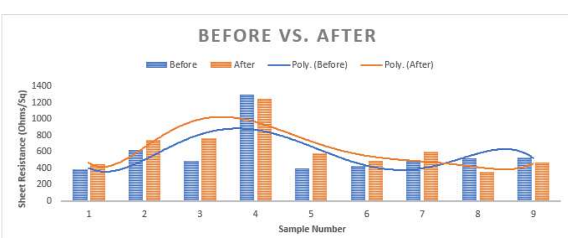

Fig. 2 Before and after measurement results for each sample. Polynomial fit lines of six degrees are shown for both the before and after results

A comparison test was also run to extract the Person coefficient between the two populations. The results of the comparison test are described in Table 1. below. The resulting high Person coefficient of .8801 indicates a high positive correlation between the two results.

TABLE I
Comparison Test

	Before	After
Before	1	0
After	.8801	1

The results from measuring the control sample with no PET backing was that the sheet resistance measured before was 526 ohms/sq while the sheet resistance measured after was 1532.33 ohms/sq.

V. Conclusion

Based on the p-value of 0.2947, the data suggest that the null hypothesis, that the two-population means are zero, is failed to be rejected. The optimal etch time was not fully investigated; however, there is a strong indication that ITO is fully removed after approximately 30 seconds based on conductivity tests completed during experimentation. All samples patterned in this work had ITO etched in areas that were desired to be etched. A high Person correlation number indicates that this method for patterning has a non-significant impact on sheet resistance. An almost three times increase in sheet resistance for the control concludes that having no PET backing removes the ITO and increases resistivity. This patterning method offers an alternative approach to rapidly prototype-patterned ITO on PVDF designs.

References

[1] A. Lu, J. Sun, J. Jiang and Q. Wan, "One-Shadow-Mask Self-Assembled Ultralow-Voltage Coplanar Homojunction Thin-Film Transistors," in *IEEE Electron Device Letters*, vol. 31, no. 10, pp. 1137-1139, Oct. 2010.

[2] I. O. Pariy et al., “Poling and annealing of piezoelectric Poly(Vinylidene fluoride) micropillar arrays,” *Materials Chemistry and Physics*, vol. 239, p. 122035, Jan. 2020.

[3] M. Lora, J. S. Lim, and M. A. McHugh, “Comparison of the Solubility of PVF and PVDF in Supercritical CH_2F_2 and CO_2 and in CO_2 with Acetone, Dimethyl Ether, and Ethanol,” J. Phys. Chem. B, vol. 103, no. 14, pp. 2818–2822, Apr. 1999.

[4] K. Sakamoto, H. Kuwae, N. Kobayashi, A. Nobori, S. Shoji, and J. Mizuno, “Highly flexible transparent electrodes based on mesh-patterned rigid indium tin oxide,” *Sci Rep*, vol. 8, no. 1, p. 2825, Dec. 2018.

[5] N. N. Tan, D. T. Hung, V. T. Anh, K. BongChul, and K. HyunChul, “Improved patterning of ITO coated with gold masking layer on glass substrate using nanosecond fiber laser and etching,” *Applied Surface Science*, vol. 336, pp. 163–169, May 2015