# Study of Screen Printed Polymer and Ceramic Based Electrode on P(VDF-TrFE) Flexible Film

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***Abstract*—This study reports the development of a reliable sensing P(VDF-TrFE) film sensor for the flexible structure sensing technology using a screen printing method. Good bonding between P(VDF-TrFE) and the structure is crucial for high voltage generation capability. In order to develop such a system, P(VDF-TrFE) film sandwiched electrical conductive electrodes were screen printed on the flexible structure. Silver palladium and polymer silver pastes were applied separately as an electrode material, Electrode quality test and FeSEM (Field Emission Scanning Electron Microscopy) were conducted on the post heat treated system to compare the bonding quality between the P(VDF-TrFE) film and the electrodes. Here, we demonstrate that the polymer silver forms a stronger bonding with the P(VDF-TrFE) film than the silver-palladium. The former also exhibits a lower electrical resistance than the latter electrode material.**

***Index Terms*— Flexible Piezoelectric PVDF, Silver Electrode, Bonding Strength, Polymer Coating, Thick-Film Technology.**

## I. INTRODUCTION

Flexible electronic applications attract great attention to consumer smart electronic products, due to properties such as low-cost production, lightweight, flexibility, and low processing temperature. They are well-matched with electronic printing technologies allowing low-cost fabrication with large-scale and low-scale production. Nowadays many inkjet printing and screen-printed micro device for sensing, smart sensors, energy harvesting applications were presented [1-5]

Piezoelectric polymer energy harvesting system mostly consists of three units: - piezoelectric layer, electrodes for signal conditioning of piezoelectric layer, and substrate for holding piezoelectric layer and making a role as an energy harvesting system [6-8].

In the previous research, they are several researchers study the bonding strength characteristics between the piezoelectric layer and electrode with the substrate which it is important in the piezoelectric device for energy harvesting application [9-10].

Se-Gi Park and Hui-Yun Hwang have fabricated gold and silver electrodes for PVDF film sensors using plasma sputtering method. They used pull-off tests and SEM (Scanning Electron Microscope) to study the adhesion strength with the thickness of the electrode. Their study concluded that the thickness of the electrode affected the adhesion strength for the fabrication of an electrode on the PVDF film [11]. Therefore, the bonding strength characteristics between electrodes and a piezoelectric layers such as P(VDF-TrFE) material and a flexible substrate such as polyethylene terephthalate (PET) substrate are important to produce high performance and reliable piezoelectric polymer energy harvesting.

In this paper, we study the bonding strength characteristics of the piezoelectric P(VDF-TrFE) prepared by the screen printing method using adhesion tape test and FeSEM (Field Emission Scanning Electron Microscopy) characterization.

## II. EXPERIMENTAL METHODS

### *A. Materials and Specimen*

P(VDF-TrFE) powder ( Kureha, Japan) was used for the fabrication piezoelectric film by using a screen printing method, and the electrodes property was shown in Table 1. The fabrication techniques were reported in our previous work [12]. Since screen printing method is the lowest cost to fabricate good performance piezoelectric P(VDF-TrFE) film, electrodes were fabricated on the P(VDF-TrFE) film for the study of the bonding characteristics between electrodes and the P(VDF-TrFE) film with PET substrate according to the type of the electrodes. Screen printing parameters were listed in Table 2.

### *B. Experimental Methods and Equipment*

In order to study the screen printing effect of the electrode on P(VDF-TrFE) film with PET substrate, the surfaces were examined using Field Emission Scanning Electron Microscopy (FE-SEM, accelerating voltage = 3 kV, Model: Merlin, Carl Zeis AG).

After Fe-SEM surfaces were examined, the crack test was performed for investigating whether visual crack on surface cause electrical short in between the P(VDF-TrFE) film, top, and bottom electrodes.

After the crack test, electrical output was observed using digital oscilloscope when an impact of force applied onto fabricated P(VDF-TrFE) film to investigate the failure surfaces for finding the relationship between low quality of fabricated electrodes and bonding strength.

Table 1
Electrode Properties [13]

| Properties | Polymer silver (LEED-DT1201) | Silver palladium (LEED-DT08020-H) |
|---|---|---|
| Sheet resistance | 0.09 Ω/sq | 30 mΩ/sq |
| Solid content | 60 ± 2% | 83± 2% |
| Tape pull (3M Tape #600) IPC TM-650 | No Ag transfer | Ag transferred |
| Chemical composition (In %) | | |
| Ag | 45±2 | 80±2 |
| Solvent | 46±2 | 20±2 |
| Resin | 9±2 | - |

Table 2
Heat Treatment Conditions for Screen-Printed Electrodes

| Layer | Drying condition | Duration |
|---|---|---|
| Top & Bottom electrode | Infrared, 60°C | 15 min |
| | & | |
| | Oven 150°C | 15 min |

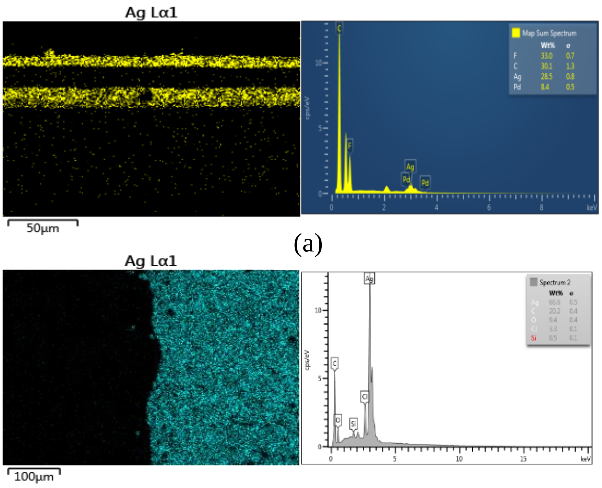
## III. Results

### A. Electrodes bonding surface observations

Figure 1 (a) showed the EDS spectrum map of layered silver polymer electrode and layered of palladium silver electrode [Figure 1(b)] are successfully printed on the Melinex substrate.

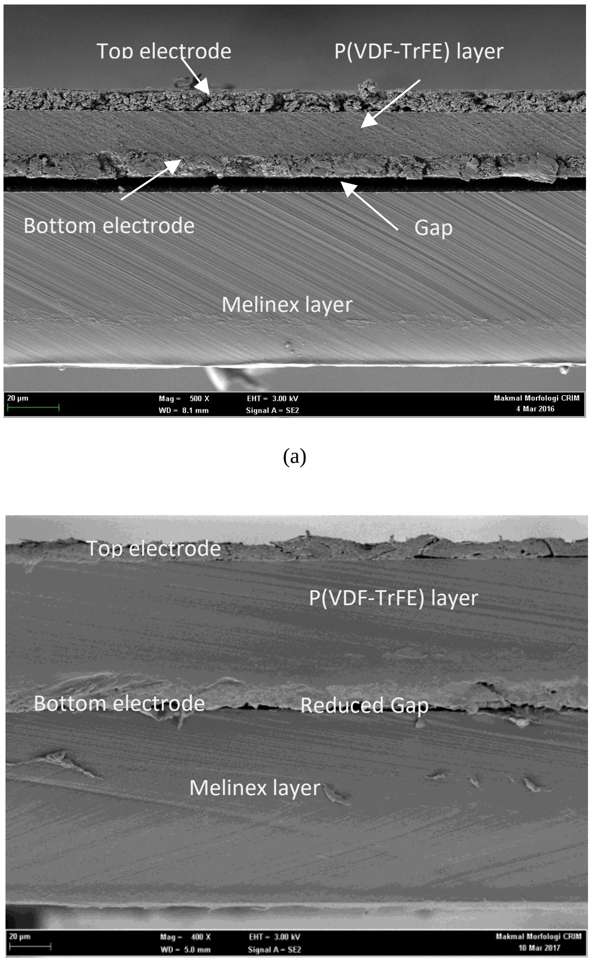
The bonding condition between electrodes and P(VDF-TrFE) film with a PET substrate with respect to the type of electrodes are shown in Figure 2. By analyzing the Fe-SEM images in Figure 2 (a), it shows that there is the presence of air gap using silver-palladium electrode where we can conclude that weak bonding condition between the electrode and PET substrate. To overcome this problem, polymer silver-based electrode was used as shown an improvement of reducing the air gap in between electrode and PET substrate in Figure 2 (b) with its measure layer of thickness in Table 3.

A further test, we did mechanical test method using pressure sensitive tape (3M Tape #600) to determine the adhesion bonding strength quality for both types of electrodes and followed the procedure as stated in the standard of IPC TM-650 (Association Connecting Electronics Industries : TM 2.4.1.E) [14]. Figure 3 (a) shows present of the silver-palladium electrode on the test surface of the tape and Figure 3(b) shows no transfer of polymer silver electrode under the same test. This result shows polymer silver electrode is the best option to be used in P(VDF-TrFE) thick film application.



(a)
(b)

Figure 1: EDX Map: (a) Cross –section layered of silver-palladium electrode; (b) Top surface layered of polymer- silver electrode



(a)
(b)

Figure 2: FeSEM image: (a) silver palldium electrode; (b) polymer- silver electrode

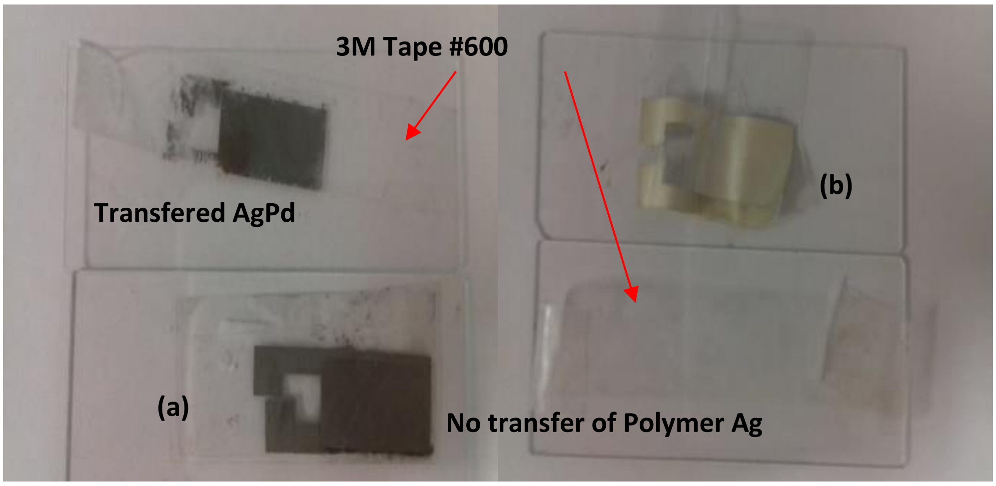



Figure 3: Mechanical Test Method: (a) silver palladium electrode; (b) polymer- silver electrode

Table 3
Measured Layer Thicknesses

| Thickness layer name / µm<br>Type of electrode | Bottom electrode | P(VDF-TrFE) | Top electrode |
|---|---|---|---|
| Silver palladium | 10.50 | 17.64 | 9.38 |
| Silver polymer | 9.78 | 60.08 | 9.78 |

### *B. Electrode Quality Test and Electrical Output Observations*

Figure 4 is the results of electrode quality test by measuring the resistance values against the electrode surface area. It clearly shows no electrical short circuit between the top electrode and bottom electrode with P(VDF-TrFE) film when there is the presence of resistance values. Therefore, we choose polymer silver electrode as the type of top and bottom electrode because its resistance value is smaller than silver palladium electrode and lower curing temperature with optimum performance. Then, we tested Polymer Ag-P(VDF-TrFE)-PET with a single step when tested under impact force as shown in Figure 5 with a voltage peak-to-peak about 3.7V.

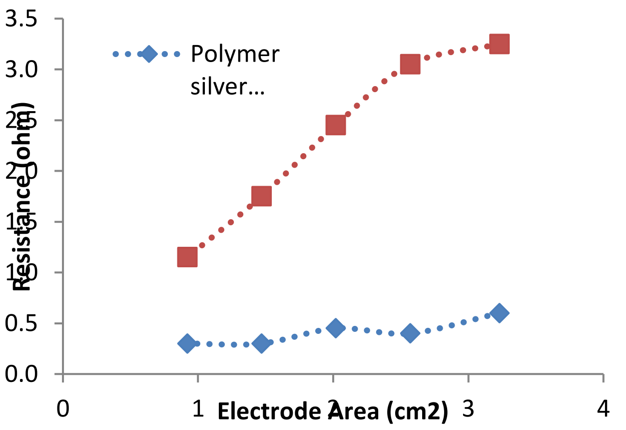



Figure 4: Electrode resistance versus electrode area

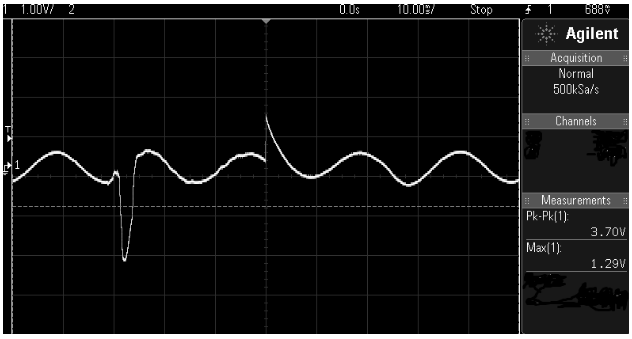



Figure 5: Instantaneous output voltage of Polymer Ag-P(VDF-TrFE)-PET single step when tested under an impact force

## IV. CONCLUSION

This study investigated the bonding condition of polymer-based compared to ceramic-based electrode printed on P(VDF-TrFE) film with PET as the flexible substrate. The quality of bonding is dependent on the type of electrodes that screen-printed on the flexible substrate. The result of the performance shows that polymer-based electrode is better adhesion than ceramic based silver-palladium electrode.

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