Study of the Adhesion Properties of the Electrode and the Piezoelectric Film-Type Sensor

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Abstract

PVDF film sensor embedded tactile sensing systems have been used due to their flexible and adaptable characteristics to curved surfaces. For reliable sensing, PVDF film sensor must be firmly fixed to a specific location of the substrate because the deformation of the substrate must be transmitted well to the PVDF film sensor. Therefore, adhesion of the substrate and the film sensor is an important factor. We implement adhesion test between the film and the electrode. The electrodes were fabricated on the film by plasma sputtering method. With gold and silver coated PVDF films, pull-off tests and SEM (Scanning Electron Microscope) were conducted to figure out the adhesion characteristics between the electrode and the film according to the type and thickness of the electrode. Adhesion strength between the electrode and PVDF films increased as the plasma sputtering duration increased and seems to be saturated to the certain value.

Introduction

The piezoelectric sensors have been widely used in many fields and modified to various form (Cheong *et al.*, 1999; Pierre, 2001; Yu *et al.*, 2002). Piezoelectric sensor embedded tactile sensing system generally consists of three parts - Piezoelectric elements, electrodes for detecting electric signals of piezoelectric elements, and substrate for protecting piezoelectric elements and making a role as a sensor structure (Shrine & Schomburg, 2008; Park *et al.*, 2014). Therefore, the adhesion characteristics between electrode and piezoelectric element as well as electrode and substrate are important in the piezoelectric sensor (Lee *et al.*, 2003; Zhang *et al.*, 2004; Kwon *et al.*, 2013). In this study, we analyzed the adhesion properties between the electrode and the piezoelectric element (PVDF film) by pull-off tests and SEM (Scanning Electron Microscope).

Experimental methods and results

Materials and specimen

The PVDF film of CS-244 (Fils co., Korea) was used for the piezoelectric element and the related property was shows in Table 1. Since Ar gas plasma sputtering as a kind of a physical vapor deposition (PVD) method is widely used to fabricate thin film with high film quality and uniform thickness, electrodes were fabricated on the PVDF film for the adhesion test between the electrode and PVDF film by Ar gas plasma sputtering method with respect to the type and thickness of electrodes. In this study, gold and silver were considered and sputtering time was controlled from 50s to 400s to make electrodes with various thicknesses. Other sputtering conditions were listed in Table 2.

Table 1: Mechanical properties of piezoelectric film-type sensor

Properties	Values
Tensile strength	11.7~14.1MPa
Density	1.78(Mg/m^3)
Piezoelectric constants	d_{31} : 22(pC/N) d_{32} : 2(pC/N) d_{33} : 35(pC/N)

Table 2: Plasma sputtering conditions for fabricating electrodes

Parameter	Values
Vacuum	0.06 torr
Current	30mA
Sputtering time	50s,100s,200s,300s and 400s

Experimental methods and equipment

In order to investigate the effects of electrode thickness on the adhesion characteristics between the electrode and PVDF film, electrode thickness changes should be measured with respect to the sputtering time. In this study, the electrode thickness was measured using a FIB (Focused Ion Beam) system (LYRA 3 XMH, Tescan, Czech Republic).

After the measurement of the electrode thickness, adhesion tests were performed for investigating adhesion characteristics between the electrode and the PVDF film. Adhesion tests were conducted under ISO - 4624 test standard reference. Equipment used in the experiment was a universal mechanical testing machine (AG-IS 5kN, Shimadzu Co., Japan), and loading speed was 0.1 mm / min.

Figure 1 shows schematic configuration of adhesion tests. PVDF films with fabricated electrodes by plasma sputtering method were adhesively bonded onto the test jigs (Jig1 and Jig2), and then cut out the film along the outer surface of Jig1. PVDF films with Jigs were fixed into the testing machine and pull-off force was applied with 0.1mm/min of loading speed.

After the adhesion test, surfaces were observed using a FE-SEM (S-4800, Hitachi, Japan) to analyze failure surfaces for finding the relationship between failure configurations, film quality of fabricated electrodes, and adhesion strength.

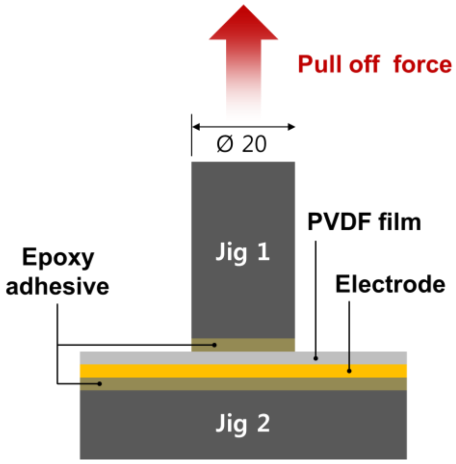

Figure 1: Schematic configuration of adhesion tests

Results

Electrode thickness measurements

The result of measuring the electrode thickness using FIB was depicted in Table 3. The thickness of electrode linearly increased as the sputtering time increased for both of silver and gold electrodes. However, the gold electrode was thicker than the silver one within the considered range of the sputtering time.

Table 3: Thickness of electrode

Electrode	Sputtering time (s)				
	50	100	200	300	400
Silver (nm)	20	54	77	102	150
Gold (nm)	25	61	112	150	200

Adhesion test results and surface observations

Figure 2 shows the adhesion strength between the gold electrode and PVDF film with respect to the electrode thickness. Adhesion strength increased as the thickness of the gold electrode increased up to 61nm, and then decreased. If the thickness was larger than 112nm, adhesion strength was kept almost constant. The highest adhesion strength was 0.4MPa when the thickness was 62nm.

By analyzing the SEM photos shown in Figure 3, the film quality of fabricated gold electrodes and failure surfaces can be differentiated with respect to the electrode thickness. The gold electrode with the thickness of 25nm had non-uniform surface morphology and film quality, but uniform and smooth surfaces were observed when the thickness was larger than 61nm. In addition, some part of the gold electrode was remained on the failure surface of PVDF film with the thickness of 61nm, and this was not observed in other cases. Therefore, it can be concluded that the adhesion strength depends on the film quality of fabricated electrodes and failure mode.

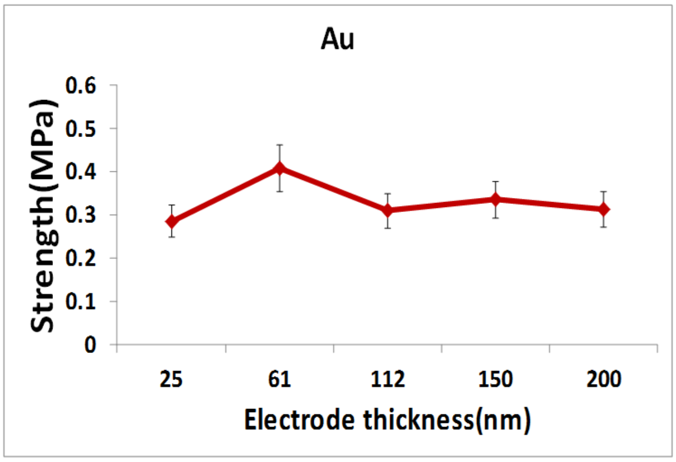

Figure 2: Adhesion test result of Au electrode

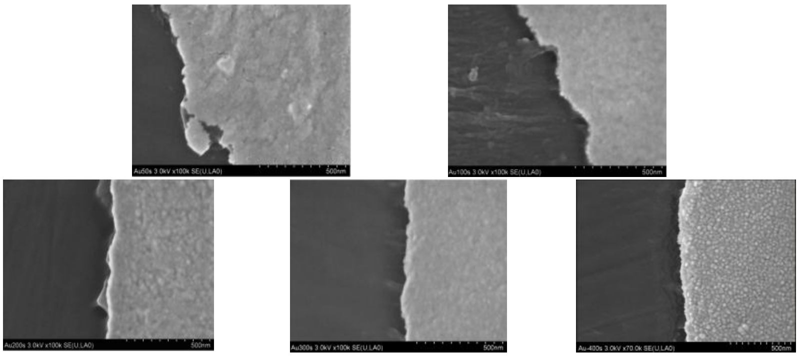

Figure 3: Fractured surface images with respect the electrode hardness

Figure 4 and Figure 5 are results of adhesion test between the silver electrode and PVDF film and SEM observation. Adhesion strength increased as the thickness increased up to 77nm, but decreased again. The highest adhesion strength was 0.48MPa when the thickness was 77nm.

In order to analyze the adhesion properties, failure surfaces were observed. The 20nm and 54nm electrodes were not fully developed and had low adhesion strength. Silver electrode with the thickness of 77nm had good film quality, but uniformity became worse if the electrode thickness was larger than 102nm. So, the adhesion strength increased, and then decreased with respect to the electrode thickness.

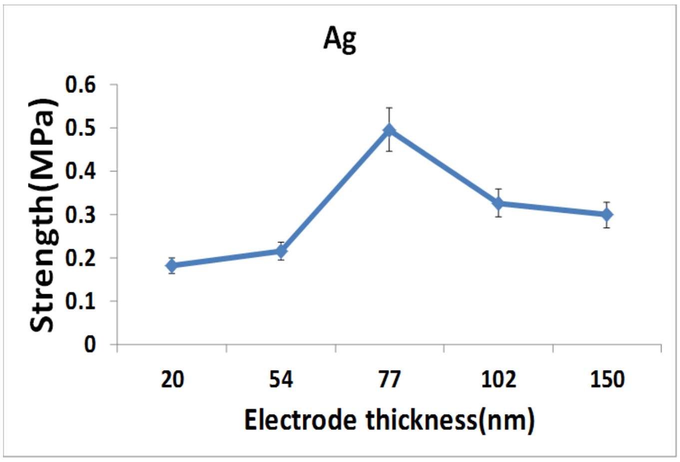

Figure 4: Adhesion test result of Ag electrode

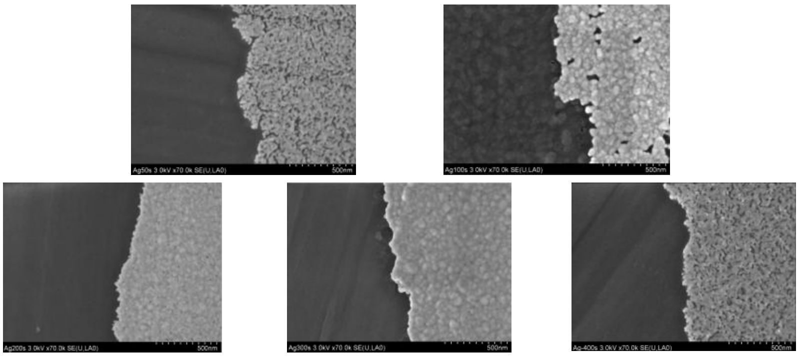

Figure 5: Fractured surface images with respect the electrode hardness

Conclusion

This study investigated the adhesion properties of the electrode and the PVDF film for piezoelectric tactile sensors. Adhesion strength was depending on the type and thickness of fabricated electrode on the PVDF film. The optimal electrode thickness could be determined from experiments, and the reasons were suggested using observation results of failure surfaces.

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