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Investigation of anti-stiction coating for ohmic contact MEMS switches with thiophenol and 2-naphthalenethiol self-assembled monolayer

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ABSTRACT

Anti-stiction coating with a conductive self-assembled monolayer (SAM) formed by π-conjugated bonds was investigated for ohmic contact microelectromechanical system (MEMS) switches with low-load contacts. SAMs of thiophenol (C_6H_5SH, TP) or 2-naphthalenethiol ($C_{10}H_7SH$, 2NT) were coated on Au samples with different surface roughness to investigate the effects of the surface asperities on the adhesion force and contact resistance. The adhesion force was measured using a silicon tipless cantilever in the relative humidity range of 10–85% and the contact resistance was measured in the contact force range of 0–70 μN using a conductive tipless cantilever coated with Au for the SAM coated samples and compared with those for a Au sample surface. The adhesion force measurements indicate that the TP and 2NT coatings can prevent a liquid meniscus from forming on device surfaces due to their hydrophobic character caused by the protruding aromatic group. In addition, it was confirmed that these coatings could reduce van der Waals forces more than Au coating. Contact resistance measurements revealed that an electric current begins to flow with smaller contact force for TP and 2NT coated samples than for Au coated samples. The measured contact resistances of the SAM and Au coated samples were comparable. Based on these results, SAMs of TP and 2NT have excellent potential as anti-stiction coating for MEMS switch contacts.

1. Introduction

In recent years, microelectromechanical system (MEMS) switches have gained significant attention due to their very small structural size and superior performance. Such devices provide high isolation when switched open, low insertion loss when closed, and can be operated at very low power consumption [1]. MEMS switches are usually categorized by the switch contact method: ohmic contact type (direct metal-to-metal contact) [2–4] and capacitive contact type (metal–insulator–metal contact) [5–7]. Ohmic contact MEMS switches generally utilize the physical contact of metal electrodes with low contact resistance to achieve low insertion loss when actuated. Thus, ohmic contact MEMS switches can be operated from DC to RF frequency with isolation defined by the coupling capacitance of the electrodes when switched open [8]. However, stiction is a major source of concern for ohmic contact MEMS switches [8–10], and occurs when the surface adhesion forces are higher than the mechanical restoring force of the movable switch contact electrode. The most common causes of adhesion are capillary, electrostatic, chemical, and van der Waals forces [9,11], all of which are strong with respect to the scale of MEMS switches, especially capillary force, which is a dominant factor in the air. The surfaces of silicon, silicon nitride and the typical metals employed in MEMS devices become hydrophilic due to oxidation in the ambient air. Therefore, an attractive force occurs from the capillary force generated by formation of a liquid meniscus by water vapor across the MEMS switch gap, and stiction occurs. Many researchers have proposed reducing the surface adhesion force by novel switch design [8,12,13], appropriate selection of switch contact materials with less adhesion [14,15], or device sealing with inert gases [16].

One attractive approach to tackle the stiction problem is to provide low-energy surface coating in the form of a hydrophobic self-assembled monolayer (SAM) on the MEMS device surface [9,17–20]. This chemical surface treatment has attracted much attention as a simple and low-cost anti-stiction coating technique for MEMS devices. However, because the most common hydrophobic SAMs are formed by essentially insulating σ-bonds, electron conduction in these SAM coatings is suppressed. On the other hand, Au coating, which is difficult to oxidize, can also reduce the capillary force caused by formation of a liquid meniscus [21]. However, thin organic insulating contaminant films can be easily deposited

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Table 1
Sample film deposition method, thickness, surface roughness and H_2O contact angle.

Sample	Deposition method	Thickness (nm)	rms roughness (nm)	H_2O contact angle (°)
Au (20 nm)	Sputtering-deposited	20	0.84	89
TP/Au (20 nm)	Liquid phase-deposited	Monolayer	2.08	91
2NT/Au (20 nm)	Liquid phase-deposited	Monolayer	2.26	92
Au (100 nm)	Sputtering-deposited	100	5.15	89
TP/Au (100 nm)	Liquid phase-deposited	Monolayer	4.58	91
2NT/Au (100 nm)	Liquid phase-deposited	Monolayer	5.07	92
SiO_2	Vapor-deposited	15	0.44	<5

on the Au surface in air [22,23]. Therefore, these coatings may not be suitable as anti-stiction coatings for MEMS switches with low-load contact.

Recently, the characterization of SAMs formed by π-conjugated bonds using electrochemical techniques have been reported [24–27]. SAMs such as thiophenol (TP; C_6H_5SH) and 2-naphthalenethiol (2NT; $C_{10}H_7SH$) can be expected to serve as anti-stiction coatings for ohmic contact MEMS switches due to their highly ordered structures, rich π electron densities, affinity of sulfur to Au, and hydrophobic character caused by the protruding aromatic group. However, the contact angles of water on these SAMs are smaller than those on hydrophobic SAMs formed by σ-bonds [28,29]. To our knowledge, the adhesion force in a humid environment and contact resistance under low-load contact conditions of these SAM-coated surfaces have yet to be investigated.

In this investigation, the adhesion force is measured using a Si tipless cantilever in a controlled humidity range of 10–85% for TP and 2NT SAM coatings deposited on Au films to investigate their anti-stiction performance. The contact resistance is also measured using a conductive tipless cantilever coated with Au in the load range of 0–70 μN to determine the applicability of these coatings to MEMS switches with low-load contact. The results are compared with those obtained for the Au sample surface.

2. Experiment

2.1. Sample preparation

Table 1 shows the sample deposition methods, film thicknesses, surface rms roughnesses, and H_2O contact angles used in this study. All the SAMs used in experiments were TP and 2NT (Tokyo Chemical Industry Co., Ltd.). Millipore water (>18 MΩ cm) was used to prepare the aqueous solutions. Two different film thickness Au samples (20 and 100 nm) were prepared to investigate the effects of surface roughness on the adhesion force and contact resistance. Au films were deposited by sputtering on Si wafers with 5-nm-thick titanium underlayers. SAM samples were then prepared by coating TP or 2NT on the Au film samples; a Au sample pretreated with piranha solution (3:1 conc. H_2SO_4:H_2O_2) was immersed in a 2 mM solution of TP or 2NT in ethanol for 24 h [30,31]. After adsorption of the thiol, the samples were rinsed with ethanol and Millipore water. Fig. 1 shows AFM surface profiles and top views of the SAM and Au samples, which confirm that large crystal grains grow on the samples deposited with a 100-nm-thick Au layer. In addition, a SiO_2 film sample with hydrophilic characteristics was prepared for comparison with the hydrophobic samples. SiO_2 film was deposited on a Si wafer using a vapor-phase deposition technique for molecular

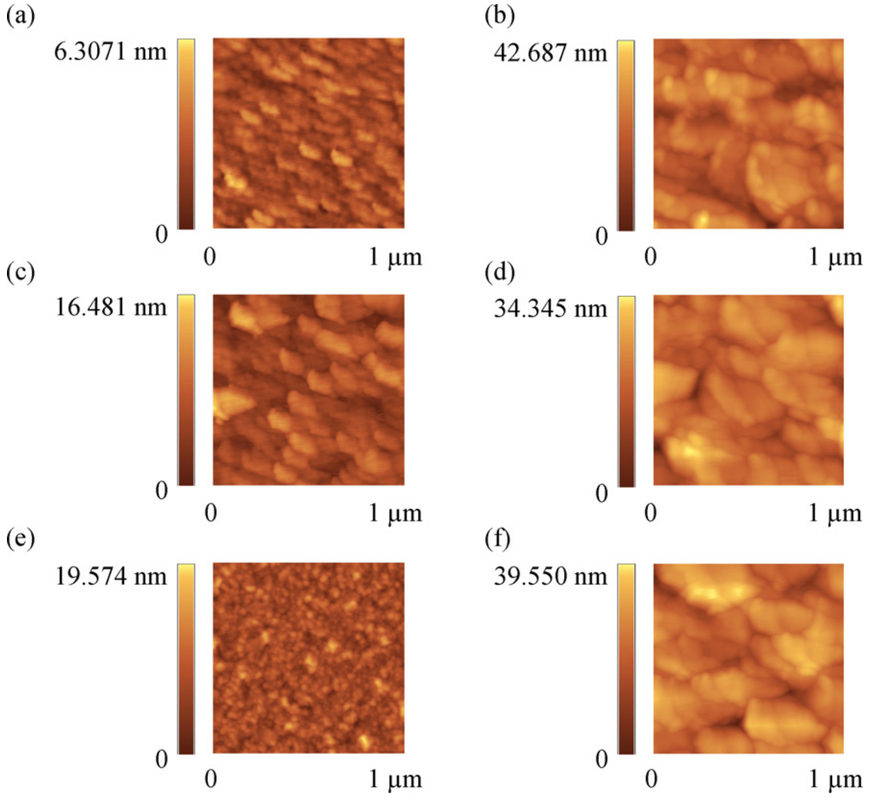

Fig. 1. AFM surface profiles and top views: (a) Au film (20 nm thick); (b) Au film (100 nm thick); (c) TP film on Au (20 nm thick) surface; (d) TP film on Au (100 nm thick) surface; (e) 2NT film on Au (20 nm thick) surface; (f) 2NT film on Au (100 nm thick) surface.