

An investigation into the role of self-assembled monolayers of silane in UV nano-imprint lithography

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Abstract:

Progress of UV nano-imprint lithography has been hampered by the generation of defects upon de-bonding of the cured resist from the stamp (so called de-molding stage). Self-assembled monolayers of silane molecule have been widely used to reduce the de-bonding energy which in turn decreases the probability of defect generation. In this work we conducted a comprehensive study to investigate the role of silane molecules in reducing the de-bond energy. Two different fluorinated silane molecules with identical head groups but hydrophobic tails of different lengths coated on silicon wafers were investigated the results were compared to untreated silicon. F₁₃-TCS denotes silane with a longer tail and F₃-TCS has a shorter tail length. Total surface energy, its dispersed and polar components ($\sigma_S, \sigma_S^P, \sigma_S^D$) along with receding, advancing and contact angle hysteresis (CAH) for bare silicon (Si/SiO₂) and silicon after treatments with two different silanes are presented in Table 1. Silane with a longer chain (F₁₃-TCS) reduces the surface tension from 64.15 (for bare silicon) to 11.50 mN/m whereas F₃-TCS reduces the surface tension only to 15.47 mN/m. Lateral force variations versus various normal loads applied measured by atomic force microscopy are shown in Figure 1. From these measurements we found that F₁₃-TCS silane reduces the friction coefficient from 0.18 (for SiO₂ on SiO₂) to 0.11 whereas F₃-TCS is less effective and reduces the friction coefficient to only 0.16.

Surface energy and friction coefficient of each surface were correlated with the de-bonding energies on a flat as well as stamps with vertical sidewalls shown in Figure 2. On a flat surface (blank stamp) the silane with a longer chain length (F₁₃-TCS) reduced the de-bonding energy by ~0.32% while silane with shorter chain length (F₃-TCS) reduced the de-bonding energy by only ~18%. However, when stamps with grating structures are used, silanation of the surface plays a more significant role in decreasing the de-bonding energy. Silanation of the grating silicon stamps with F₁₃-TCS decreased the de-bonding energy by ~0.55% whereas the stamps coated with F₃-TCS experienced a reduction of ~0.38% in the de-bonding energy. When F₃-TCS and F₁₃-TCS are compared together there is a ~0.17% more reduction in de-bonding energy on a flat surface when F₁₃-TCS is used. This reduction becomes larger and reaches almost 0.27% for grating stamps. The excess decrease in the de-bonding energy on grating stamps is associated with the decrease in the friction coefficient on the sidewalls of the stamp (besides surface energy) when the surface is coated with silane.

Table 1 Total, dispersed and polar Surface energies ($\sigma_S, \sigma_S^P, \sigma_S^D$) along with receding, advancing and contact angle hysteresis (CAH) for bare silicon (Si/SiO₂) and silicon after silane treatments.

	σ_S (mN/m)	σ_S^P (mN/m)	σ_S^D (mN/m)	Receding CA	Advancing CA	CAH
Bare silicon	64.15	36.76	27.39	N.A	N.A	N.A
F ₃ -TCS	15.47	2.25	13.22	110.1	64.7	45.4
F ₁₃ -TCS	11.50	1.22	10.28	122.0	77.0	45.0

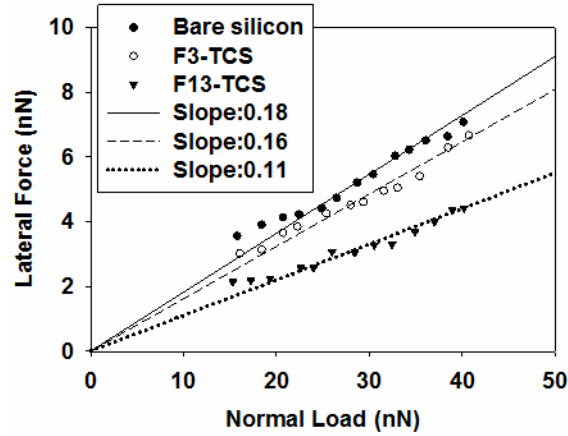


Figure 1: Friction vs. normal force curves measured by LFM for bare silicon and silicon treated with silanes. Friction coefficients are determined from the slope of these curves.

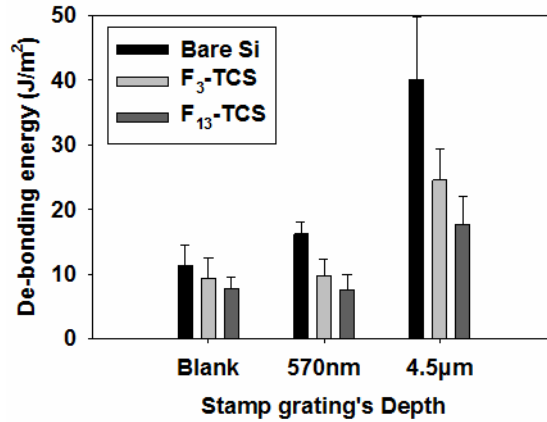


Figure 2: De-bonding energy of a UV resist imprinted on bare silicon and silicon treated with different silanes. De-bonding energy was measured on a blank (non-structured) stamp as well as 570nm and 4.5µm deep grating stamps with identical periods of 15µm and grating widths of 5µm.