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Van der Waals interactions between silica spheres and metallic thin films created by e-beam evaporation

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HIGHLIGHTS

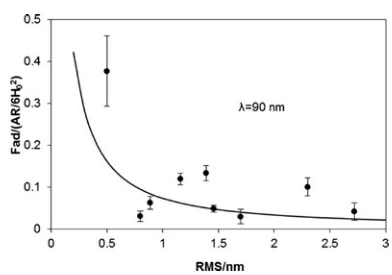
- Thin metallic films on silicon with roughness 0.5–3 nm are obtained using e-beam.
- Dispersion forces for non-contacting samples agree semi-quantitatively with theory.
- The experimental adhesion forces agree with theory suggesting the regular roughness.
- In the range of $RMS = 0.5–3$ nm, adhesion force decreases by 3–40 times.
- Humidity of 20–40% did not affect the adhesion force of Al and Cu samples.

GRAPHICAL ABSTRACT

The dependence of $Fad/(AR/6H_0^2)$ vs. $RMS2$ for the interaction between a smooth silica particle and a rough metallic film is shown. The theoretical curve was calculated using the following equation [25,26]:

$$Fad = \frac{AR}{6H_0^2}\left[\frac{1}{1+58R\cdot RMS/\lambda^2}+\frac{1}{(1.82\cdot RMS/H_0)^2}\right]$$

As predicted from theory, the surface roughness significantly reduces the adhesion force. Samples with $RMS = 0.5–3$ nm demonstrate an adhesion force Fad that is 3–40 times smaller than that between smooth samples. This figure demonstrates agreement between experimental results for a non-regular surface roughness and this theoretical formula.



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ABSTRACT

The long-range and adhesion forces between a molecularly smooth silica sphere and a relatively smooth thin metallic film have been measured by atomic force microscopy (AFM) operating in contact mode. The majority of the dispersion force measurements have been done with root mean square (RMS) roughness of more than 10 nm. This paper investigates lower roughness to prove or disprove theory of the van der Waals force for irregularly distributed size of asperities. Metallic films of Cu, Al, and Ag were obtained by coating silicon wafers using an electron beam evaporation (e-beam) method. The e-beam deposition rates were within the range of 0.6–1.2 Å/s at vacuum pressures between 2×10^{-6} and 3×10^{-6} mbar. The developed coatings had peak-to-peak distance ranges of 80–120 nm and 1–2 μm. Long-range attractive forces were obtained from the extending portion of the force/distance curves measured between a silica particle attached to the AFM cantilever and the metallic film surface. Certain samples demonstrated an attractive force much larger than the theoretically calculated dispersion force, which we attribute to an electrostatic image force. For other samples, the extending curves were comparable with the theoretical dispersion forces, especially when the curves were shifted by a distance of 1.82 RMS. Adhesion forces were measured from the retracting portion of the force/distance curves. For peak-to-peak distance near

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