Supplementary Material for

Controlling macroscopic friction through interfacial siloxane bonding

Liang Peng *et al.*

S1: Details about BEM calculations

In the BEM model, the linearly elastic equations that describe contact deformations are solved based on the half-space method[1,2]. It should be noted that the resolution of the AFM topography measurements is limited by either the sharpness of the AFM tip or the pixel size, both approximately 20 nm. The BEM model can therefore not describe contact structures at length scales below this limit[3–5]. However, recent experiments suggest that at these smallest scales, atom-by-atom wear occurs; if so, this would minimize the contact structure at unresolved length scales; our analysis is based on this assumption being valid[6,7].

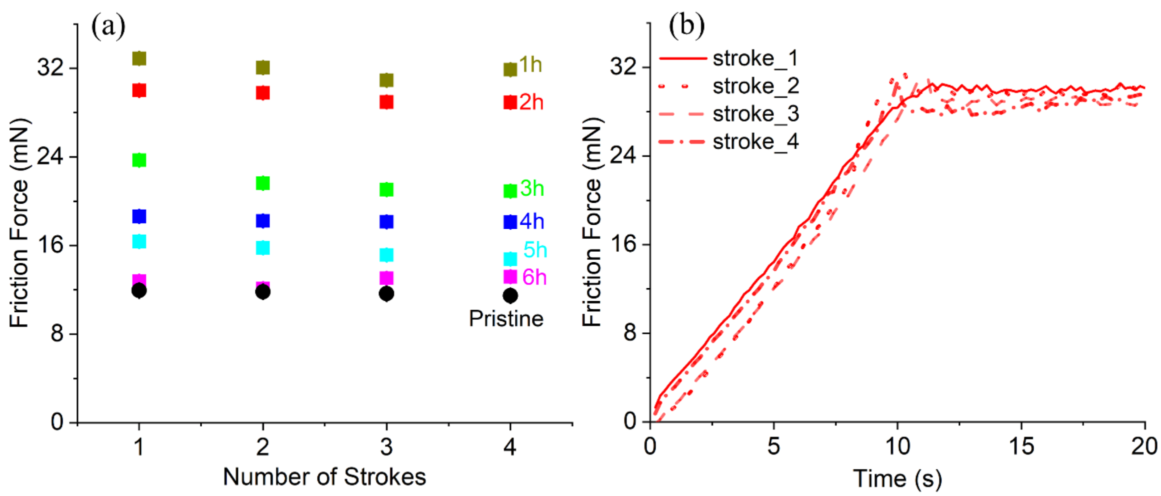

Fig. S1. Friction force as a function of the number of sliding strokes. (a) The friction force was measured on the pristine wafer (black symbols) and on the plasma-cleaned surfaces after different drying times as indicated by the labels. The measured friction forces without any hysteresis indicate a minimal influence of wear. (b) One example shows how the kinetic friction force is defined in the steady state for the plasma-cleaned surface after two hours of nitrogen drying.

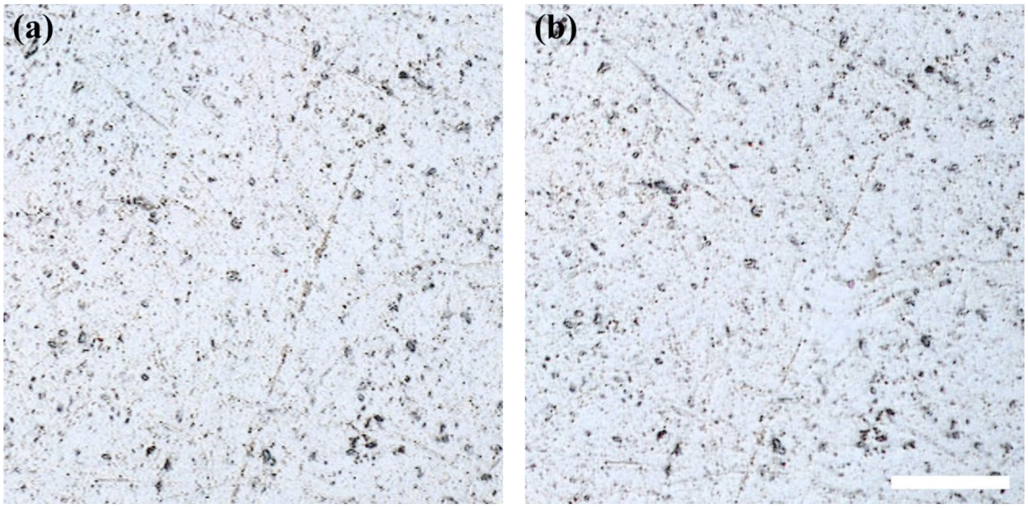

Fig. S2. Optical images of the silicon ball recorded before (a) and after (b) the friction measurements shown in Fig. 2, measured using a laser-scanning confocal profilometer (Keyence VK-X1000). Although wear of the silicon wafer is largely avoided by performing each stroke at a previously untouched region, a quite small wear scar is visible, within which the sliding conditions likely result in a stable surface chemistry state. It is confirmed that this wear of the sphere impacts our results minimally as the friction measurements (Fig. S1a) are quite stable. Scale bar, 20 μm.

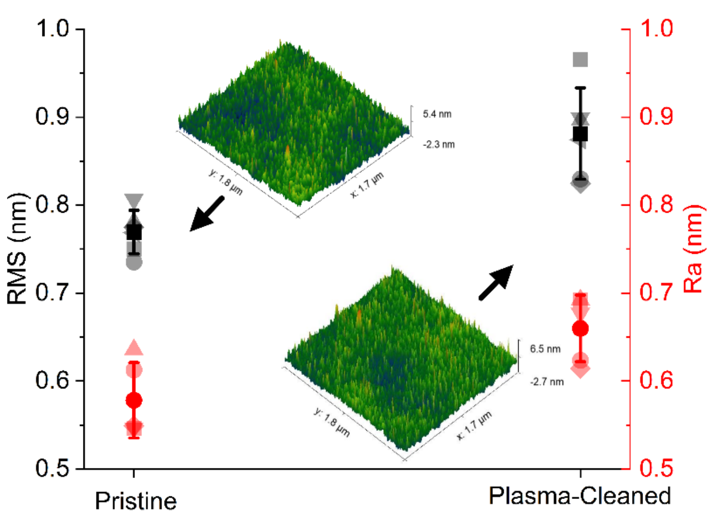

Fig. S3. Root-mean-squared (RMS) and average roughness (Ra) of the silicon wafer surfaces before and after plasma cleaning, as obtained by tapping mode atomic force microscopy (AFM, Dimension Icon, Bruker) with Si tips (RTESPA-300, Bruker). Different data points correspond to randomly distributed measurement spots with a size of 1.7×1.8 μm^2 on one wafer. The insets display the corresponding surface 3D images. The plasma treatment only results in a 15% increase in RMS, corresponding to a 14% increase in Ra, which can be regarded as a negligible roughness change compared with the roughness of the silicon ball at the interface.

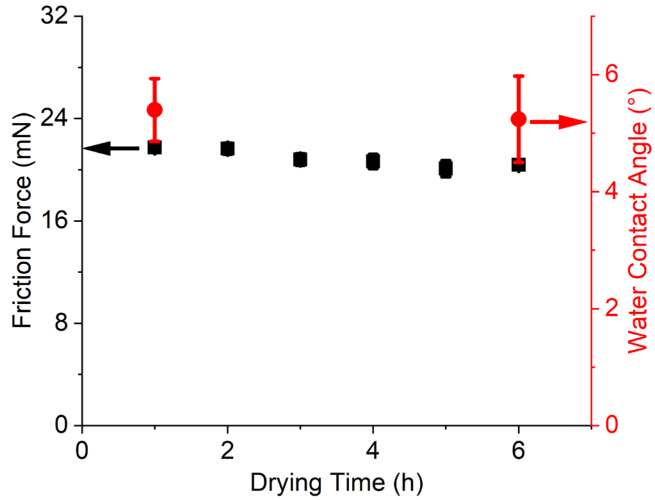

Fig. S4. Friction force (black symbols) and water contact angle (red symbols) as a function of aging time at 40% relative humidity. The relative humidity inside the chamber is controlled by a humidifier (MHG100, proUmid), which could provide a constant gas flow of 12 L/min and control the relative humidity with an accuracy of ±0.8%."

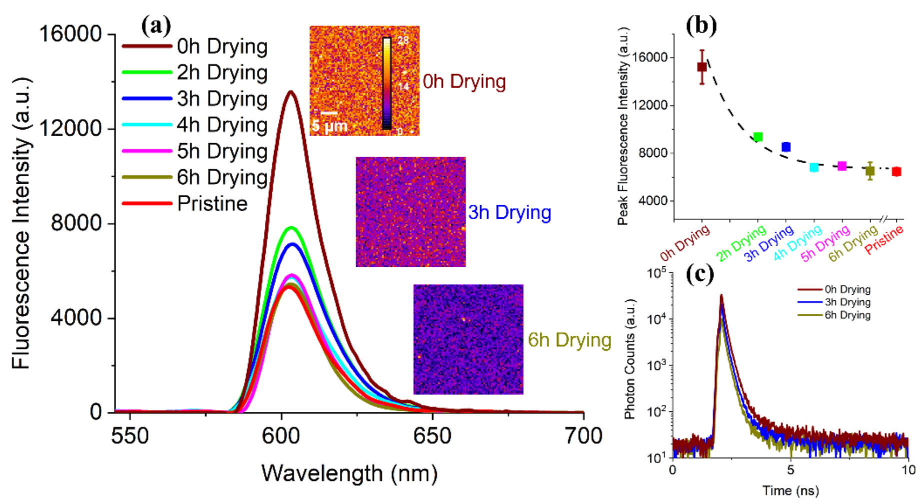

Fig. S5. Fluorescence spectra and images of the plasma-cleaned wafer surfaces after different nitrogen drying times, as well as the fluorescence spectra and images of the pristine wafer surface as indicated by the labels (a). Each spectral line represents the average result of three measurements. The insets in (a) show the fluorescence images on the plasma-cleaned surfaces after 0, 3, and 6 hours of nitrogen drying, respectively. The corresponding mean peak fluorescence intensity is displayed in (b). Line in (b) is drawn through the data points to guide the eye. (c) shows the fluorescence decay curves, from which the estimated fluorescence lifetimes are 179ps, 182ps, and 169ps after drying for 0h, 3h, and 6h, respectively.

References

[1] Akchurin A, Bosman R, Lugt PM, Van Drogen M. On a model for the prediction of the friction coefficient in mixed lubrication based on a load-sharing concept with measured surface roughness. Tribol Lett 2015;59:1–11. https://doi.org/10.1007/s11249-015-0536-z.

[2] Müser MH, Dapp WB, Bugnicourt R, Sainsot P, Lesaffre N, Lubrecht TA, et al. Meeting the Contact-Mechanics Challenge. Tribol Lett 2017;65. https://doi.org/10.1007/s11249-017-0900-2.

[3] Gujrati A, Khanal SR, Pastewka L, Jacobs TDB. Combining TEM, AFM, and Profilometry for Quantitative Topography Characterization Across All Scales. ACS Appl Mater Interfaces 2018;10:29169–78. https://doi.org/10.1021/acsami.8b09899.

[4] Jacobs TDB, Ryan KE, Keating PL, Grierson DS, Lefever JA, Turner KT, et al. The effect of atomic-scale roughness on the adhesion of nanoscale asperities: A combined simulation and experimental investigation. Tribol Lett 2013;50:81–93. https://doi.org/10.1007/s11249-012-0097-3.

[5] Jacobs TDB, Pastewka L. Surface topography as a material parameter. MRS Bull 2022;47:1205–10. https://doi.org/10.1557/s43577-022-00465-5.

[6] Leriche C, Xiao C, Franklin S, Weber B. From atomic attrition to mild wear at multi-asperity interfaces: The wear of hard Si3N4 repeatedly contacted against soft Si. Wear 2023;528–529:204975. https://doi.org/10.1016/j.wear.2023.204975.

[7] Hsia F, Hsu C, Peng L, Elam FM, Xiao C, Franklin S, et al. Contribution of capillary adhesion to friction at macroscopic solid-solid interfaces. Phys Rev Appl 2022:Accepted.