

Enhancing Self-Assembled Monolayer Formation on Gold-Coated Silicon via Femtosecond Laser-Induced Surface Structuring

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Abstract

This study investigates femtosecond laser-induced surface structuring as a strategy to enhance self-assembled monolayer (SAM) formation on gold-coated silicon substrates for microsystem and sensor-interface applications. Micro- and submicron-scale grooves were fabricated on silicon using femtosecond laser processing, followed by Cr/Au thin-film deposition and functionalization with 11-mercapto-1-undecanol at concentrations from 10^{-3} to 10^{-6} M. Atomic force microscopy showed that laser-textured substrates produced higher surface roughness and more effective molecular coverage, particularly at low thiol concentrations. X-ray photoelectron spectroscopy confirmed Au–S bonding through S 2p peaks near 162.5 eV, indicating successful thiol chemisorption. The results demonstrate that femtosecond laser surface texturing can improve molecular adsorption on gold-coated silicon and provide a practical route for developing functional surfaces in MEMS, microsensors, and related microsystem technologies.

1. Introduction

The construction of monolayers in a clear and immediate method on surfaces has enabled them to offer an innovative approach to complicated nanoscale architecture (Prashar 2012). This process is essential to numerous physical, chemical and biological processes. Bottom-up structures are fundamental to nanoscience and has the capability of revolutionizing multiple organizations. Researchers involved in molecular electronics maintain that molecular self-assembly could be used to make new types of transistors and switches taking the place of the present dependence on silicon electronics. The pharmaceutical industry is keen to embrace self-assembly principles to enhance the delivery process of medication (Xiang et al. 2016; Casalini et al. 2017; Kim and Yoo 2021; Hayashi and Latag 2025; Shakiba et al. 2017; Paliwal et al. 2022). SAMs are ideal model systems for providing valuable opportunities to further our understanding of phenomena governed by the competition between intermolecular interactions, molecule–substrate interactions, and molecule–solvent interactions. These phenomena include molecular ordering and growth, adhesion, corrosion, lubrication, and wetting. This is a result of the ability to tailor both head and tail groups of the constituent molecules (Prashar 2012; Ulman 1996; Choi et al. 2022; Ramachandran et al. 1996; Ulman 1995). The most investigated SAMs today is alkanthiols ($\text{HS}(\text{CH}_2)_n\text{CH}_3$) self-assembly onto gold that can be prepared by adsorption of di-n-alkyl disulfides from dilute solutions (Ulman 1996; Löfgren et al. 2016; Kato et al. 2002; Noh and Hara 2000; Yuan et al. 2011; Bain et al. 1989). Initially a focus on long-chain alkanethiols was prompted by their amphiphilic properties, which were employed to control wetting properties (Bain and Whitesides 1988; Ulman et al. 1992; Colorado and Lee 2003). Immediately the possibility of these compounds for surface modification became apparent, a substantial amount of research on alkanethiols on various noble metals commenced (Kumar et al. 1994). Studies carried out recently were driven by possible applications of SAM on (bio)sensor, interface and nanofabrication development (Hayashi and Latag 2025; Guo and Li 2014).

The microfabrication by photolithography and soft lithography process to create patterned SAMs of alkanethiolates on gold films permits applications in the semiconductor industry. These processes depend on precise micropatterns or nanopatterns on the planar or nonplanar surfaces that give access to many applications to create numerous commercial devices. Having gained substantial interest from researchers in the field they do however have certain limits. Although it is a well-established process, photolithography has certain restrictions as a result of optical diffraction, the requirement for high-energy radiation for insignificant features, and the expensive cost of complex equipment. In addition, it is not possible to use it on non-planar surfaces (Xia and Whitesides 1998; Whitesides et al. 2001; Qin et al. 2010; Slaughter et al. 2017; Ul-Haq et al. 2013). Although soft lithography techniques, including hot embossing, microtransfer molding (μ TM), solvent-assisted micromolding (SAMIM), micromolding in capillaries (MIMIC), microcontact printing (μ CP), and replica molding (REM), have been widely investigated, they still face several challenges that hinder their successful commercialization and large-scale implementation. The fundamental concern, which restricts high-resolution registration in soft lithography, is the interference of elastomeric materials. The pairing, sagging, swelling, and shrinking of the elastomer could prompt the micropatterns or nanopatterns in the stamp or mold to become distorted. This process could create errors as a result of dust particles, inadequate substrate adhesion, inadequate stamp release, and prepolymer bubbles. Reactive ion etching is generally employed to remove the thin polymer film that exists in soft lithography. This could, however, affect minor features (Whitesides et al. 2001; Qin et al. 2010; Ul-Haq et al. 2013).

In order to improve the chemical, mechanical and physical properties of the gold surface, a process to modify this surface employs the formation of a nanostructure layer on the gold surface to enhance its bonding with thiols. On the surface of gold, nanostructured microgrooves and submicrogrooves can be produced by employing femtosecond laser (FSL) micromachining. The gold's surface texturing will enhance its surface area and chemical activity, and the submicrogrooves will act as cavities for trapping the targets (Al-Gawati et al. 2022; Zhang et al. 2011; Guo et al. 2020; Goya et al. 2017; Samanta et al. 2020; Li et al. 2023).

This study aims to develop a femtosecond laser-based surface structuring approach to improve SAM formation on gold-coated silicon substrates. By introducing micro- and submicron-scale grooves before Au thin-film deposition, the work examines how laser-induced surface morphology influences thiol adsorption, Au–S bonding, and molecular layer uniformity. The structured and unstructured substrates are compared using AFM and XPS to clarify the relationship between surface texturing and SAM formation. This approach is intended to support the design of functional gold-coated silicon interfaces for microsensors, MEMS platforms, and surface-based microsystem applications.

2. Experimental part

The surface of silicon wafers was patterned with micro- and sub-microgrooves using a femtosecond laser (FSL) micromachining system (Workshop of Photonics, Lithuania). A schematic of the laser surface texture is shown in Fig. 1. The substrates were mounted on a computer-controlled motorized XY

stage with a high positioning resolution, allowing precise fabrication of microgrooves and sub-microgrooves. A femtosecond laser source with a fundamental wavelength of 1026 nm and pulse duration of 220 fs was employed. The setup comprised an optical path integrated with a machine-vision camera for real-time process monitoring, a high-accuracy positioning stage, and micromachining SCA software. The laser pulses beam with an average laser power of 22 mW, 0.22 μ J pulse energy, and repetition rate of 100 kHz was focused onto the silicon surface using a spherical focusing lens with a numerical aperture (NA) of 0.28.

The resulting sub-microgrooves exhibited an average width of $0.27 \pm 0.042 \mu\text{m}$, and depth of $257.139 \pm 39.284 \text{ nm}$, with an inter-groove spacing of $0.57 \pm 0.020 \mu\text{m}$. Figure 2 illustrates the SEM image for the sub-microgrooves textured by femtosecond laser (FSL) processing. The post-fabrication cleaning was carried out by immersing the samples in piranha solution ($\text{H}_2\text{SO}_4\text{:H}_2\text{O}_2$, 3:1) for 5 min to remove the ablated debris, followed by rinsing with ethanol and deionized water then it was dried at 250°C for 10 min. Further surface cleaning was achieved by sequential ultrasonication in acetone, ethanol, and deionized water (10 min each). The microstructure of the produced sub-grooves (width, and spacing) was investigated using field emission scanning electron microscopy (FE-SEM), while the depth was estimated via atomic force microscopy (AFM).

The Au thin film was deposited on the patterned surface using a high-vacuum thermal evaporation system (Oerlikon Leybold Vacuum, Germany). Thin film deposition began with the application of a 5-nm chromium (Cr) layer onto cleaned silicon substrates to serve as an adhesion layer between the silicon surface and the subsequent gold (Au) layer. A 40-nm gold film was then deposited on top of the Cr layer using thermal evaporation. The gold-coated silicon substrates were immersed at room temperature for 1 hour in ethanolic solutions of 11-mercapto-1-undecanol at concentrations ranging from 10^{-3} to 10^{-6} M to form self-assembled monolayers (SAMs). This process was carried out in the dark to avoid photodegradation. SAMs were prepared on both laser-structured and unstructured gold surfaces under the same conditions. To evaluate the formation and quality of the SAMs, surface characterization was performed using MultiMode Atomic Force Microscopy (AFM) (Nanoscope V, Veeco-Bruker) in tapping mode. Surface roughness and nanoscale morphology were analyzed to confirm successful SAM formation across varying concentrations.

Additional characterization was conducted using X-ray Photoelectron Spectroscopy (XPS) (JEOL, Japan) to further validate the chemical composition and surface binding of the SAM layers.

3. Results and Discussions

3.1. Surface Morphology Characterization Using Atomic Force Microscopy (AFM)

Figure 3 shows a schematic representation of an ordered arrangement of densely packed self-assembled monolayers of thiol molecules (11-mercapto-1-undecanol) on a gold surface. The thiol (11-

mercapto-1-undecanol) molecules possess a proper anchoring thiol group that forms a covalent bond with the gold surface. Moreover, they have a backbone chain, which stabilizes the film and has a characteristic thickness of about 1.791 nm for a single monolayer, as illustrated in Fig. 3. Besides, they have a hydroxyl (-OH) group at the end site, which plays a vital role in the chemistry of the surface film.

Figure 4 shows 3D AFM images of the topography of the pure gold-coated silicon and gold-coated silicon surface functionalized with SAM of the target thiol at various concentrations before and after femtosecond laser texture. These images provide clear insight into how the root mean square (RMS) surface roughness (R_s) varies with thiol concentration, thereby reflecting the effect of molecular adsorption on surface structuring.

As illustrated in Fig. 4(a), the bare gold substrate displayed a homogeneous and relatively smooth morphology with a low R_s value of 1.52 ± 0.68 nm, indicating minimal surface irregularities. However, after SAM formation, a distinct increase in roughness was observed, confirming the adsorption and organization of thiol molecules onto the gold surface. The AFM results demonstrated R_s values of 3.09 ± 0.23 , 3.32 ± 0.6 , 2.66 ± 0.43 , and 2.74 ± 0.27 nm for substrates incubated in ethanol solutions of 11-mercapto-1-undecanol at concentrations of 10^{-6} , 10^{-5} , 10^{-4} , and 10^{-3} M, respectively.

A significant change in morphology and an increase in surface roughness was observed in the gold samples incubated with increasing concentrations from 10^{-6} M to 10^{-5} M, as reflected in the measured R_s values shown in Fig. 4(b) and (c). This increase in roughness can be attributed to the thiol having a high affinity for gold. The thiol functional group strongly binds to gold surfaces, leading to their preferential deposition in areas with higher exposure.

Additionally, the long-chain structure of 11-mercapto-1-undecanol enhances surface roughness by increasing the gold surface's textural complexity (Ballen et al. 2021). Furthermore, a considerable increase in image height can be attributed to forming a multilayer of 11-mercapto-1-undecanol molecules on the gold surface. Although the SAM of the thiol layer on the gold surface was stable, this multilayer structure alters the surface's topography compared to other thiol concentrations. Figure 4(d) shows that there was a considerable decrease in roughness, resulting in an RMS value of 2.66 ± 0.43 nm with increasing concentration of the thiol 10^{-4} M. In this case, a lower RMS value suggests a smoother and more uniform surface texture, which may be because of the filling of the empty spaces and, thus, forming a more homogeneous layer. However, the RMS surface roughness increased to 2.74 ± 0.27 nm when the concentration increased to 10^{-3} M, shown in Fig. 4(e), which was less compared to the RMS roughness of 10^{-6} M. The reduction in the surface roughness could be attributed to thiol molecules that might have filled up the existing SAM and may have smoothened the surface (Gunda et al. 2014).

On the other hand, as seen in Fig. 4(f-j) the self-assembled monolayer (SAM) is not clearly visible in the 3D images due to the presence of deep sub-microgrooves, which contribute to a significantly increased image height much greater than the typical height of a SAM layer. The surface roughness (R_s) of bare gold is measured at 73.36 ± 7.82 nm. In comparison, the R_s values for the surface-structured, gold-

coated samples immersed in thiol solutions of varying concentrations are 75.26 ± 1.71 nm for 10^{-6} M, 95.17 ± 3.44 nm for 10^{-5} M, 45.58 ± 1.55 nm for 10^{-4} M, and 47.68 ± 3.78 nm for 10^{-3} M. Figure. 5 summarize the R_s values for all samples, as measured by the AFM system, both with and without surface texture. This figure shows the R_s as a function of the thiol (11-mercapto-1-undecanol) concentrations (10^{-6} M, 10^{-5} M, 10^{-4} M, and 10^{-3} M) with grooves and without grooves of the gold substrates. The graph shows a similar behavior for the unstructured and structured samples. The laser surface structured gold-coated samples have a significant roughness value, which begins to dramatically increase with the deposition of the thiol layer in the samples with grooves at low concentrations of thiols 10^{-6} M and 10^{-5} M. On the other hand, in samples without grooves, the R_s increase with the deposition of the thiol layer but are not as significant as in samples with grooves. Increasing roughness in the case of laser-structured samples can be attributed to the microstructures, and sub-microstructures can be induced on the silicon surface using a femtosecond laser, increasing the interfacial surface area for molecular adsorption. Therefore, the surface-structured gold-coated silicon by femtosecond laser can be used in sensors as a highly sensitive surface because it enables more efficient interactions with target analytes and enhances the sensor's sensitivity (Al-Gawati et al. 2020; Al-Gawati et al. 2022). These results suggest that the surface processing of silicon substrates using a femtosecond laser creates a high-aspect-ratio, rough surface on the Si surfaces. Specifically, at low concentrations of the target thiol, this increased surface area provides more binding sites for the target analytes, resulting in improved sensitivity. This result corresponds to those observed in the study (Hayden et al. 2013) that display the rougher films' improved sensitivity to chemical sensing.

3.2 X-ray Photoelectron Spectroscopy (XPS) Analysis of Au Thin Films Functionalized with Thiol at Varying Concentrations

X-ray Photoelectron Spectroscopy (XPS) was utilized to investigate the surface chemical composition and bonding behavior of gold (Au) thin films functionalized with varying concentrations of 11-mercapto-1-undecanol (10^{-6} to 10^{-3} M), both prior to and following femtosecond laser surface structuring. The objective was to examine the binding characteristics of sulfur to gold and evaluate the impact of surface grooves on thiol adsorption. The binding energy (BE) between the gold-coated silicon wafer surface and the self-assembled monolayers (SAMs) was analyzed using X-ray photoelectron spectroscopy (XPS) with a JEOL JPS-9030 system (JEOL, Europe). All spectra were acquired using a non-monochromatic (Mg K α) X-ray source (photon energy = 1253.6 eV) under a base pressure of 9.6×10^{-9} mbar. Measurements were performed in constant pass energy mode (E_p = 10 eV) with an energy step size of 0.1 eV. The spectral data were processed using the Savitzky–Golay algorithm for peak smoothing and fitted using a non-linear Gaussian function.

Prior to femtosecond laser structuring, the S 2p core-level spectra of gold thin films functionalized with thiol revealed multiple binding energy peaks indicative of sulfur–gold interactions. At a concentration of 10^{-3} M, binding energy components were detected at 161.53, 162.24, and 162.49 eV. For the 10^{-4} M

concentration, revealed peaks at 160.03, 161.01, 161.86, and 163.01 eV. The 10^{-5} M sample exhibited peaks at 161.03, 162.14, 162.78, and 163.44 eV, while the lowest concentration (10^{-6} M) presented peaks at 160.35, 161.40, 161.95, and 162.42 eV. Across all concentrations except for 10^{-4} M, a peak near 164 eV commonly associated with unbound thiol species was observed. These results are summarized in Table 1 and are consistent with previously reported literature values (Alshammari et al. 2020; Castner et al. 1996; Lustemberg et al. 2008; Sahoo and Ke 2021). The corresponding S 2p spectra are shown in Fig. 6(a–d). Following femtosecond laser patterning, distinct modifications were observed in the S 2p spectral profiles across all thiol concentrations examined. At a concentration of 10^{-3} M, five binding energy peaks were identified at 160.95, 161.66, 162.15, 162.80, and 163.63 eV. For the 10^{-4} M sample, peaks appeared at 160.40, 161.39, 162.50, and 163.88 eV. The 10^{-5} M concentration exhibited peaks at 161.44 and 162.75 eV, while the 10^{-6} M sample showed peaks at 160.35, 160.90, 162.01, and 163.04 eV. These spectral features are indicative of thiol-gold interactions and suggest an enhancement in chemisorption following laser-induced surface structuring. A complete summary of the observed binding energy values is provided in Table 1, with corresponding S 2p spectra presented in Fig. 6(e–f).

Table 1
A comprehensive summary of sulfur binding energy peaks across different concentrations before and after surface enhancement

Sulfur	10^{-6} M	10^{-5} M	10^{-4} M	10^{-3} M
Untextured Surface	164.54	164.26	164.86	164.92
	164.03	163.44	163.01	162.49
	162.42	162.78	161.86	162.24
	161.95	162.14	161.01	161.53
	161.40	161.03	160.03	160.97
	160.35	-	-	-
Textured Surface	164.21	164.92	165.13	163.63
	163.04	162.75	163.88	162.80
	162.01	161.44	162.50	162.15
	160.90	-	161.39	161.66
	160.35	-	160.40	160.95

The presence of a prominent $S_{2p3/2}$ peak at approximately 162.5 eV across all patterned samples confirms the formation of robust Au–S bonds, consistent with metal-sulfur bonding references (binding energy $\sim$ 162.5 eV) (Al-Gawati et al. 2022). In contrast, this signature was significantly weaker or absent in unstructured samples, indicating less efficient binding. These results strongly suggest that femtosecond laser-induced surface structuring enhances the surface energy and topographical features

of the gold films, thereby promoting thiol chemisorption through increased surface area and reduced potential energy regions. Grooves formed during patterning provide energetically favorable sites for thiol molecules, encouraging their immobilization via covalent bonding.

Conclusion

This study demonstrated that femtosecond laser surface structuring can enhance SAM formation on gold-coated silicon substrates by increasing surface roughness and providing additional adsorption sites for thiol molecules. AFM analysis showed that laser-textured surfaces exhibited pronounced morphological changes and improved molecular coverage, especially at lower thiol concentrations. XPS analysis confirmed the formation of Au–S bonds, with S 2p features near 162.5 eV indicating successful chemisorption of 11-mercapto-1-undecanol on the gold surface.

The combined AFM and XPS results show that laser-induced micro- and submicron-scale grooves promote stronger surface functionalization compared with unstructured substrates. These findings indicate that femtosecond laser processing is a useful and maskless method for preparing functional gold-coated silicon interfaces. The approach has potential relevance for MEMS, microsensors, and microsystem-based chemical or biological sensing platforms.

Declarations

Author Contributions:

R.A.A. conducted the investigation and wrote the original manuscript draft. A.S.A. and R.A.A. performed data curation. M.A.A. contributed to methodology, validation, formal analysis, resources, visualization, and manuscript review and editing. A.F.A. contributed to manuscript review and editing. A.A. contributed to conceptualization, formal analysis, resources, visualization, and supervision. A.N.A. contributed to conceptualization, formal analysis, and supervision. All authors reviewed and approved the final manuscript.

Data Availability Statement:

Data available on request from the authors

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Conflicts of Interest:

The authors declare no conflicts of interest.

Ethics declaration:

Not applicable.

References

1. Al-Gawati MA, Alhazaa A, Albrithen H, Alnofiay J, Alodhayb A (2020) Effect of surface patterning using femtosecond laser on micromechanical and structural properties of micromechanical sensors. *Mater Res Express* 7:085904
2. Al-Gawati MA, Albrithen H, Alhazaa AN, Alodhayb AN (2022) Sensitivity enhancement of microelectromechanical sensors using femtosecond laser for biological and chemical applications. *Surf Interface Anal* 54:1060-1069
3. Alshammari AF, Aldosari N, Bin Qarmalah A, Muthuramamoorthy LM, Alodhayb A (2020) Detection of chemical host-guest interactions using a quartz tuning fork sensing system. *IEEE Sens J* 20:12543-12551
4. Bain CD, Whitesides GM (1988) Correlations between wettability and structure in monolayers of alkanethiols adsorbed on gold. *J Am Chem Soc* 110:3665-3666
5. Bain CD, Troughton EB, Tao YT, Evall J, Whitesides GM, Nuzzo RG (1989) Formation of monolayer films by the spontaneous assembly of organic thiols from solution onto gold. *J Am Chem Soc* 111:321-335
6. Ballen SC, Steffens J, Steffens C (2021) Stability characteristics of cantilever nano biosensors with simple and complex molecules for determination of cadmium. *Sens Actuators A Phys* 324:112686
7. Casalini S, Bortolotti AC, Leonardi F, Biscarini F (2017) Self-assembled monolayers in organic electronics. *Chem Soc Rev* 46:40-71
8. Castner DG, Hinds K, Grainger DW (1996) X-ray photoelectron spectroscopy sulfur 2p study of organic thiol and disulfide binding interactions with gold surfaces. *Langmuir* 12:5083-5086
9. Choi Y, Tran H, Lee TR (2022) Self-assembled monolayer coatings on gold and silica surfaces for antifouling applications: a review. *Coatings* 12:1462
10. Colorado R, Lee TR (2003) Wettabilities of self-assembled monolayers on gold generated from progressively fluorinated alkanethiols. *Langmuir* 19:3288-3296
11. Goya K, Yamachoshi Y, Fuchiwaki Y, Tanaka M, Ooie T, Abe K, Kataoka M (2017) Femtosecond laser direct fabrication of micro-grooved textures on a capillary flow immunoassay microchip for spatially-selected antibody immobilization. *Sens Actuators B Chem* 239:1275-1281
12. Gunda NSK, Singh M, Norman L, Kaur K, Mitra SK (2014) Optimization and characterization of biomolecule immobilization on silicon substrates using (3-aminopropyl) triethoxysilane (APTES) and glutaraldehyde linker. *Appl Surf Sci* 305:522-530
13. Guo B, Sun J, Hua Y, Zhan N, Jia J, Chu K (2020) Femtosecond laser micro/nano-manufacturing: theories, measurements, methods, and applications. *Nanomanuf Metrol* 3:26-67
14. Guo Q, Li F (2014) Self-assembled alkanethiol monolayers on gold surfaces: resolving the complex structure at the interface by STM. *Phys Chem Chem Phys* 16:19074-19090

15. Hayashi T, Latag GV (2025) Self-assembled monolayers as platforms for nanobiotechnology and biointerface research: fabrication, analysis, mechanisms, and design. *ACS Appl Nano Mater* 8:8570-8587
16. Hayden VC, Rahman SMS, Beaulieu LY (2013) Computational analysis of the effect of surface roughness on the deflection of a gold coated silicon micro-cantilever. *J Appl Phys* 113:054501
17. Kato HS, Noh J, Hara M, Kawai M (2002) An HREELS study of alkanethiol self-assembled monolayers on Au(111). *J Phys Chem B* 106:9655-9658
18. Kim S, Yoo H (2021) Self-assembled monolayers: versatile uses in electronic devices from gate dielectrics, dopants, and biosensing linkers. *Micromachines* 12:565
19. Kumar A, Biebuyck HB, Whitesides GM (1994) Patterning self-assembled monolayers: applications in materials science. *Langmuir* 10:1498-1511
20. Li N, Huang X, Dong H, Duan B, Zhu Q, Mao A, Li P, Cui B, Silvain J, Lu Y (2023) Gold-coated nanoripples produced by UV-femtosecond lasers for surface enhanced Raman spectroscopy. *Appl Surf Sci* 636:157794
21. Löfgren J, Grönbeck H, Moth-Poulsen K, Erhart P (2016) Understanding the phase diagram of self-assembled monolayers of alkanethiolates on gold. *J Phys Chem C* 120:12059-12067
22. Lustemberg PG, Vericat C, Benitez GA, Vela ME, Fainstein A, Martiarena ML, Salvarezza RC (2008) Spontaneously formed sulfur adlayers on gold in electrolyte solutions: adsorbed sulfur or gold sulfide. *J Phys Chem C* 112:11394-11402
23. Noh J, Hara M (2000) Nanoscopic evidence for dissociative adsorption of asymmetric disulfide self-assembled monolayers on Au(111). *Langmuir* 16:2045-2048
24. Paliwal H, Parihar A, Prajapati BG (2022) Current state-of-the-art and new trends in self-assembled nanocarriers as drug delivery systems. *Front Nanotechnol* 4:836674
25. Prashar D (2012) Self-assembled monolayers - a review. *Int J ChemTech Res* 4:258-265
26. Qin D, Xia Y, Whitesides GM (2010) Soft lithography for micro- and nanoscale patterning. *Nat Protoc* 5:491-502
27. Ramachandran S, Tsai B, Blanco M, Chen H, Tang Y, Goddard WA (1996) Self-assembled monolayer mechanism for corrosion inhibition of iron by imidazolines. *Langmuir* 12:6419-6428
28. Sahoo SM, Ke SC (2021) Spin-orbit coupling effects in Au 4f core-level electronic structures in supported low-dimensional gold nanoparticles. *Nanomaterials* 11:554
29. Samanta A, Wang Q, Shaw SK, Ding H (2020) Roles of chemistry modification for laser textured metal alloys to achieve extreme surface wetting behaviors. *Mater Des* 192:108744
30. Shakiba A, Zenasni O, Marquez MD, Lee TR (2017) Advanced drug delivery via self-assembled monolayer-coated nanoparticles. *AIMS Bioeng* 4:275-299
31. Slaughter LS, Cheung KM, Kaappa S, Cao HH, Yang Q, Young TD, Serino AC, Malola S, Olson JM, Link S, Häkkinen H, Andrews AM, Weiss PS (2017) Patterning of supported gold monolayers via chemical lift-off lithography. *Beilstein J Nanotechnol* 8:2648-2661

32. Ul-Haq E, Patole S, Moxey M, Amstad E, Vasilev V, Hunter CN, Leggett GJ, Spencer ND, Williams NH (2013) Photocatalytic nanolithography of self-assembled monolayers and proteins. *ACS Nano* 7:7610-7618
33. Ulman A (1995) Surface adsorption of monolayers. *MRS Bull* 20:46-51
34. Ulman A (1996) Formation and structure of self-assembled monolayers. *Chem Rev* 96:1533-1554
35. Ulman A, Evans SD, Shnidman Y, Sharma R, Eilers JE (1992) Mixed alkanethiol monolayers on gold surfaces: wetting and stability studies. *Adv Colloid Interface Sci* 39:175-224
36. Whitesides GM, Ostuni E, Takayama S, Jiang X, Ingber DE (2001) Soft lithography in biology and biochemistry. *Annu Rev Biomed Eng* 3:335-373
37. Xia Y, Whitesides GM (1998) Soft lithography. *Annu Rev Mater Sci* 28:153-184
38. Xiang D, Wang X, Jia C, Lee T, Guo X (2016) Molecular-scale electronics: from concept to function. *Chem Rev* 116:4318-4440
39. Yuan Y, Yam CM, Shmakova OE, Colorado R, Graupe M, Fukushima H, Moore HJ, Lee TR (2011) Solution-phase desorption of self-assembled monolayers on gold derived from terminally perfluorinated alkanethiols. *J Phys Chem C* 115:19749-19760
40. Zhang MY, Shadnam MR, Amirfazli A (2011) Direct laser patterning of self-assembled monolayer using elliptical laser beams: a theoretical parametric study. *Opt Laser Technol* 43:1377-1384

Figures

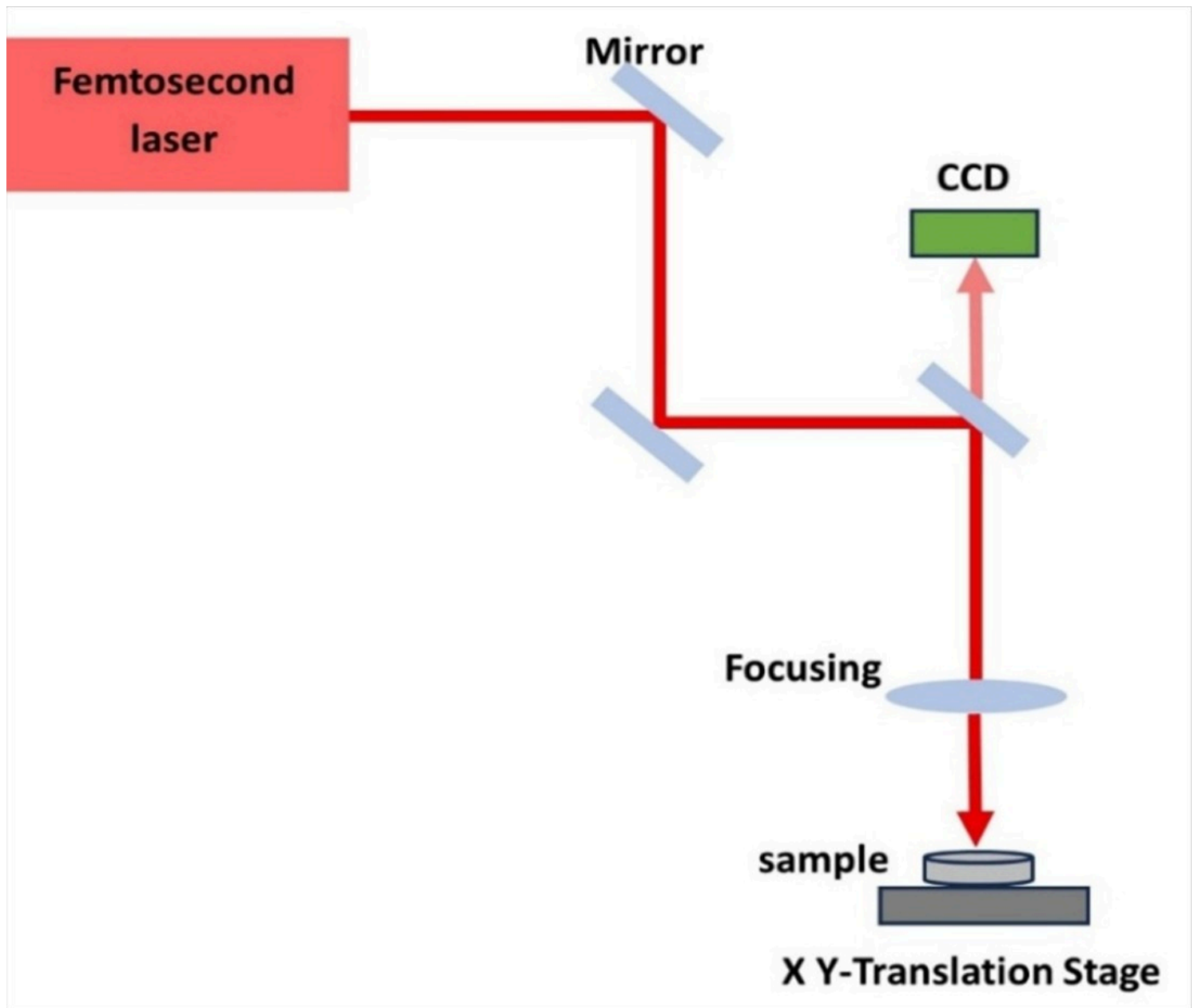


Figure 1

Laser surface texturing system.

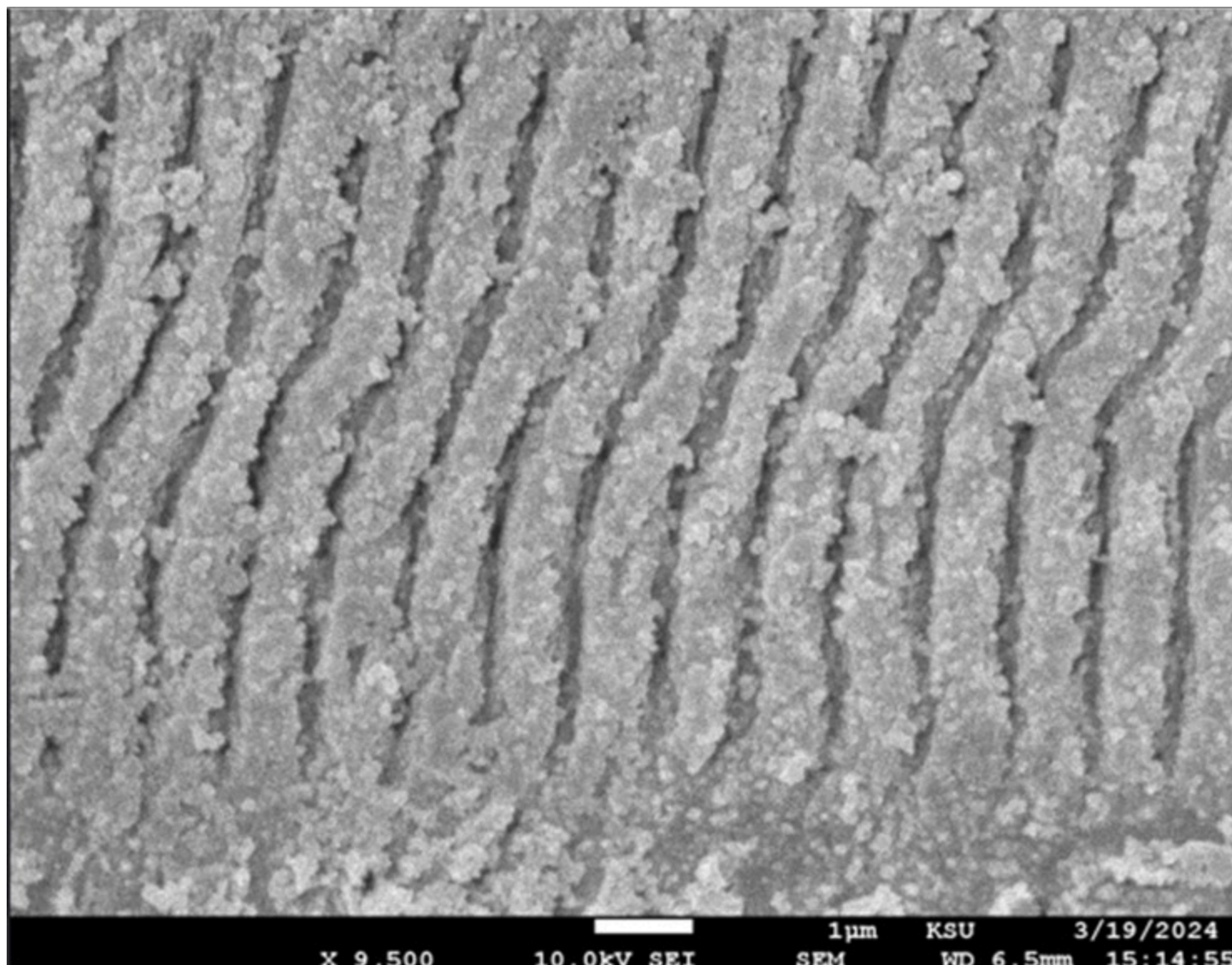


Figure 2

Scanning electron microscopy (SEM) image showing the microstructure formed on the surface of the silicon microcantilever.

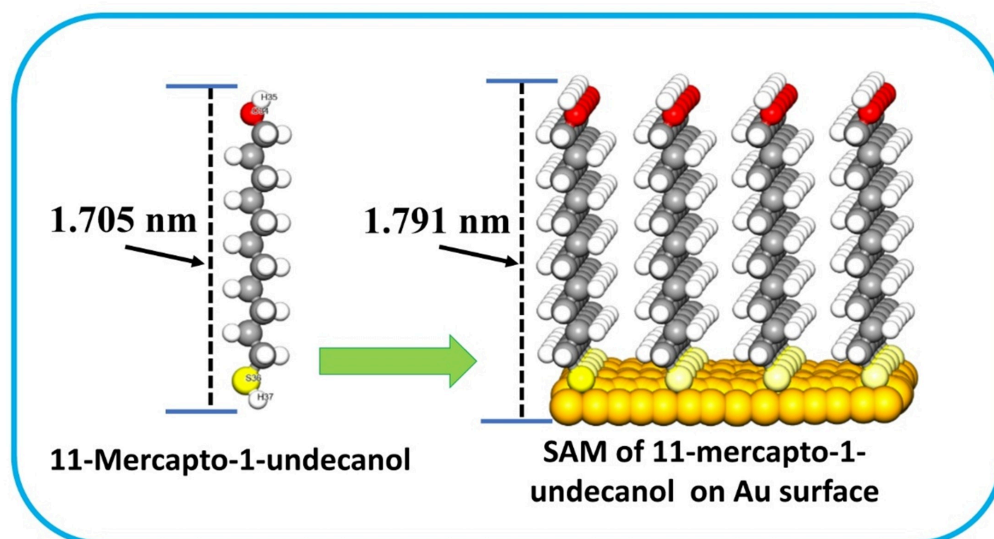


Figure 3

Schematical illustration of thiol (11-mercapto-1-undecanol) and self-assembly monolayer of thiol molecules (11-mercapto-1-undecanol) on gold surface.

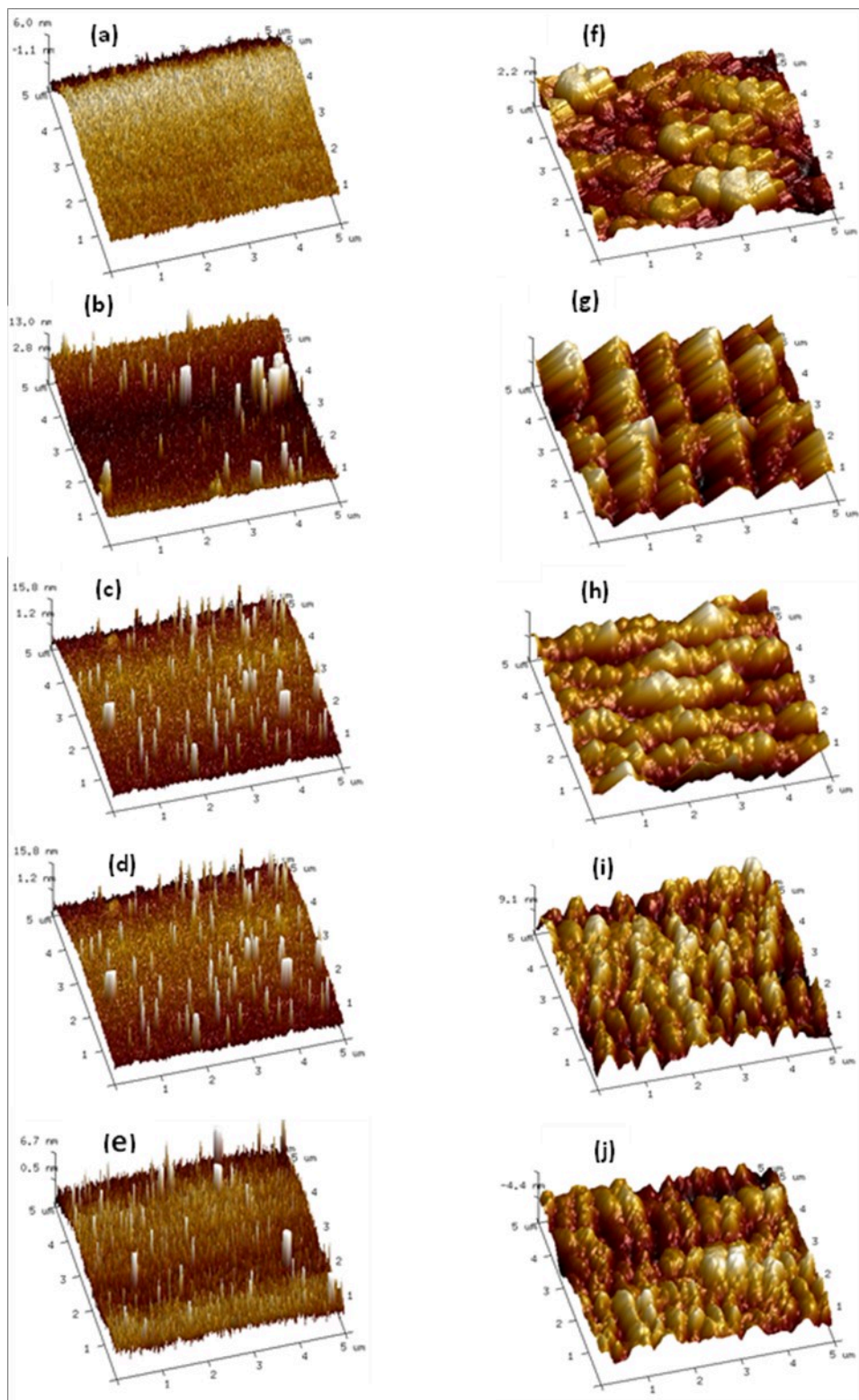


Figure 4

images obtained by means of 3D Atomic Force Microscopy (AFM) demonstrating the surface morphology of gold-coated silicon substrates before and after self-assembled monolayer (SAM) formation. (a) Surface without SAM coating and (b-e) SAM-coated surfaces with thiol concentrations of 10^{-6} , 10^{-5} , 10^{-4} , and 10^{-3} M, respectively, prior to femtosecond laser (FSL) surface texturing. (f) Surface after femtosecond laser (FSL) surface texturing without SAM coating and (g-j) surfaces after FSL

surface texturing and SAM formation with thiol concentrations of 10^{-6} , 10^{-5} , 10^{-4} , and 10^{-3} M, respectively.

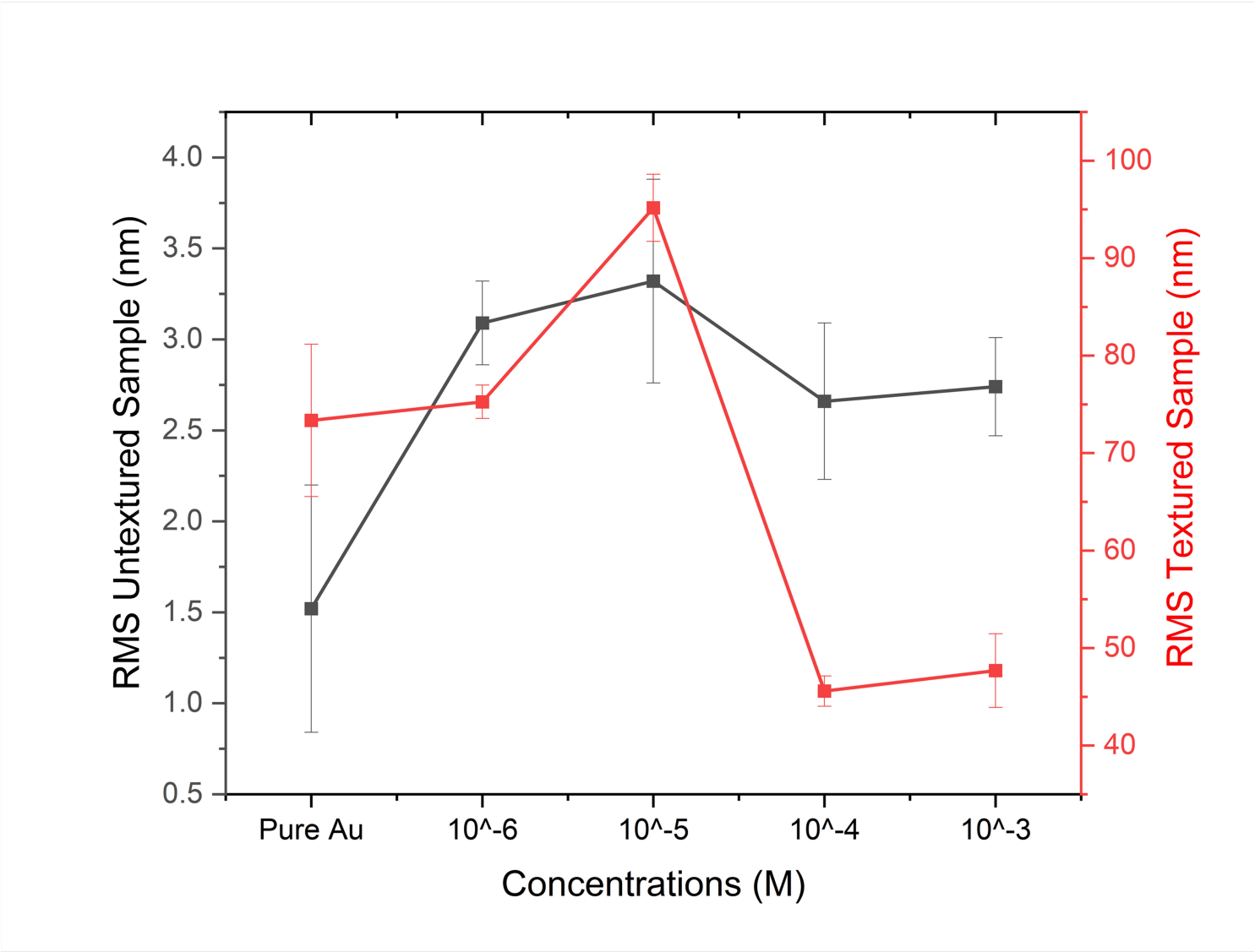


Figure 5

Root-mean-square (RMS) surface roughness as a function of 11-mercapto-1-undecanol thiol concentrations was evaluated for both femtosecond-laser-untextured and textured gold-coated silicon substrates.

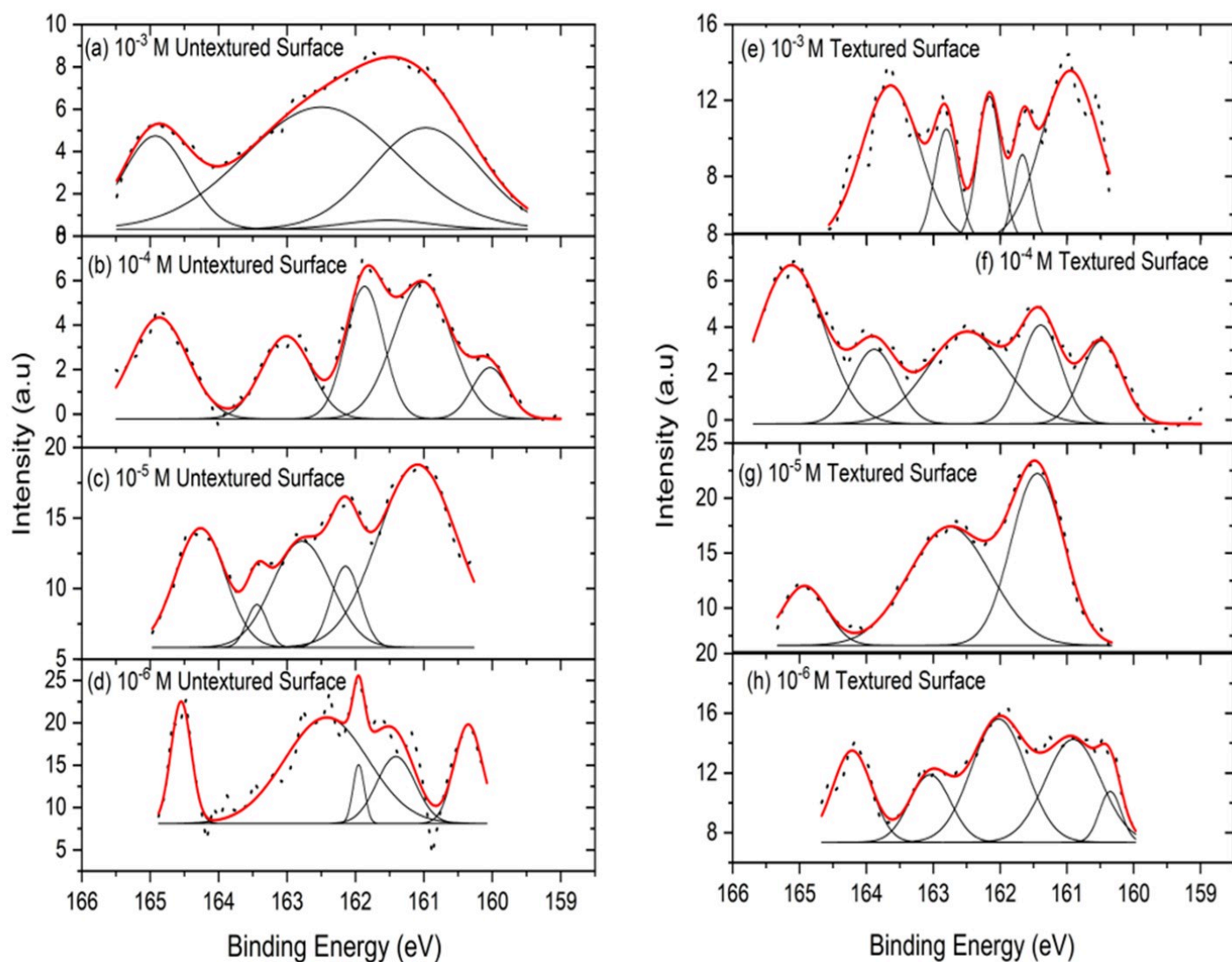


Figure 6

XPS spectrum for Au thin films modified with 11-mercapto-1-undecanol at different concentrations before and after surface texturing using femtosecond laser (FSL). Fig. 6(a–d) represent the spectra for samples modified with thiol solutions of concentrations 10^{-3} , 10^{-4} , 10^{-5} , and 10^{-6} M, respectively, while the Fig. 6(e–h) represent the spectra for the same concentrations after laser texturing. The comparison demonstrates the impact of surface texturing using femtosecond laser radiation on the chemical interaction of sulfur thiol molecules with gold surfaces.