Title: Preparation of Ultra-Thin Gold Films with Subatomic Surface Roughness

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Abstract: Nanoscale device fabrication requires control over film growth at the atomic scale. Growth conditions must be tuned in consideration of interface parameters like chemical bonding, surface free energy, and lattice matching. In metals, electronic properties may also be utilized for control of physical parameters. Quantum size effects can induce metals to spontaneously form specific shapes and sizes according to their electronic structure. Unfortunately, such electronic growth is generally known only for a few systems and is typically only stable under cryogenic conditions. In this work, we explore a recently discovered class of electronic growth systems in which metal films are grown upon the relatively inert surfaces of van der Waals crystals. In this class of materials, the electronic growth is highly stable at room temperature and actually requires higher temperature annealing to achieve proper equilibrium. We work with the Au/MoS_2 system, which shows excellent stability and can readily form discrete and atomically flat nanostructures. Here, we show how the electronic growth modes facilitate the formation of atomically flat films with nanometer scale thickness. The surface roughness of these films was found to be less than a single atom over several square microns, creating nearly perfect surfaces for studies of self-assembled monolayers or other applications.

Key Words: dichalcogenide, quantum confinement, electronic growth, self-assembly, ultra-thin films, nanostructure

Introduction

In metallic systems, self-assembled nanostructure growth can be facilitated by electronic properties of the system[1] in addition to the more traditional tuning of interface parameters like chemical bonding, surface free energy, and lattice matching. Unfortunately, the conditions which support such electronic growth have limited opportunities to a few known systems and typically require cryogenic conditions.[2-4] However, we have recently discovered that metallic films gown

on van der Waals surfaces can exhibit highly stable electronic growth modes.[5, 6] Highly stable nanostructures with atomically flat surfaces can be fabricated at or above room temperature in processes compatible with standard semiconductor fabrication techniques. However, as seen in other electronic growth systems, control over lateral extents is challenging. The quantum effects which create discrete nanostructure heights are much less effective in controlling lateral sizes beyond the nanometer scale. Developing such control is highly desired to create atomically flat surfaces which are highly prized as substrates used in a variety of scientific disciplines.[7-11]

Ultra-flat gold surfaces are highly valued for scientific investigations and nanoscale device fabrication. They are often used as substrates to study the electrical,[12-16] mechanical,[17, 18] and optical[19, 20] properties of a diverse array of samples using a variety of techniques. They are also heavily used as substrates for the formation of self-assembled monolayers due to the high affinity for thiol molecules.[7, 21-23] Due to cost and other processing issues, thin gold films are used almost exclusively. Ideally, such films are continuous, atomically flat, and have minimal grain boundaries.[22] Unfortunately, due to the weak coupling between gold and other materials, this is very difficult to achieve in practice. The highest quality gold films are usually grown on mica substrates.[24] Depending on growth conditions, such films are flat at the atomic scale but each crystalline grain spans only a few hundred nanometers.[25] Alternately, gold grown upon mica can be more continuous but with large numbers of atomic steps that contribute to surface roughness.[25, 26] Ultra-flat surfaces can also be achieved using a template-stripping process.[27] This results in lower quality continuous films that extend over larger areas than are feasible for direct growth on mica.

Creating atomically uniform films requires a combination of well-controlled growth conditions and a high degree of matching between the crystal lattice of film and substrate[28] or materials that form a wetting layer[29] to reduce strain at the interface. This limits the number of potential systems and often requires a complex growth process with intermediary layers to minimize strain and achieve uniformity. In metallic films like gold, quantum size effects arising from the electronic structure can also be used to control film growth.[5] The deposited metal spontaneously arranges itself into discrete and highly preferred thicknesses correlated with the electronic structure.[6] Local electronic energy minima occur at film thicknesses that are half integer multiples of the Fermi wavelength (λ_F), which induces an energy gap to form at the Fermi level.

However, lattice matching is still a critical feature, and the electronic energy scales are nearly always much smaller than other growth parameters, so that quantized growth processes result in metastable films or nanostructures limited to cryogenic temperatures.[2-4] Hence, quantum growth is quite rare and not compatible with most applications.

Experimental Section

MoS_2 single crystals (SPI Supplies) were attached to STM sample holder plates *ex situ* using conductive silver paste. Fresh surfaces were prepared by mechanical exfoliation shortly before insertion into the vacuum deposition chamber (base pressure 2×10^{-9} mbar) and degassed at 500K *in situ* for one hour. The substrate was then allowed to cool and held at room temperature as the Au (Alfa Aesar, 99.995%) was thermally evaporated at a rate of 0.1 Å/s as measured *in situ* using a quartz microbalance with a precision of 10%. The coverage, defined here as the nominal thickness deposited if the gold formed a homogenous and uniform Au(111) film with a bulk lattice constant, was further calibrated using STM measurements of the Au volume present on different areas of the surface. Following deposition, samples were exposed to ambient conditions for no more than thirty minutes before being transferred into an Omicron variable temperature STM system with base pressure of 7×10^{-9} mbar. Samples were then either transferred directly to the STM scanner head for measurement or annealed under vacuum at 650 K for 10 minutes on a preparation stage in accordance with previous temperature studies [5]. Annealed samples were transferred for measurement after cooling to room temperature. STM tips were electrochemically etched from a W wire in a 5 M potassium hydroxide solution with a 5 V bias.

STM measurements were performed using a variety of biases and tunneling currents. Images were typically acquired at a positive tip bias between 0.5 and 1.5 V and setpoint between 0.5 and 3 nA. Scanning parameters were varied to maintain stability as the system could spontaneously degrade during measurement. As seen in other STM studies.[5] an entire Au nanostructure would occasionally decouple from the surface during scanning. In extreme cases, scanning would remove all of the nanostructures in the scanning region, leaving vast squares of exposed MoS_2. This severely impacted tip quality, making it necessary to exchange STM tips far more frequently than usual and inhibiting lateral atomic resolution. Scanning parameters were varied as necessary to maximize stable scanning conditions and had little impact on our results so long as stability was maintained. Although investigated at length, no significant correlation was found

between scanning parameters and stability, at least for parameters useful for high quality imaging.

Results and Discussion

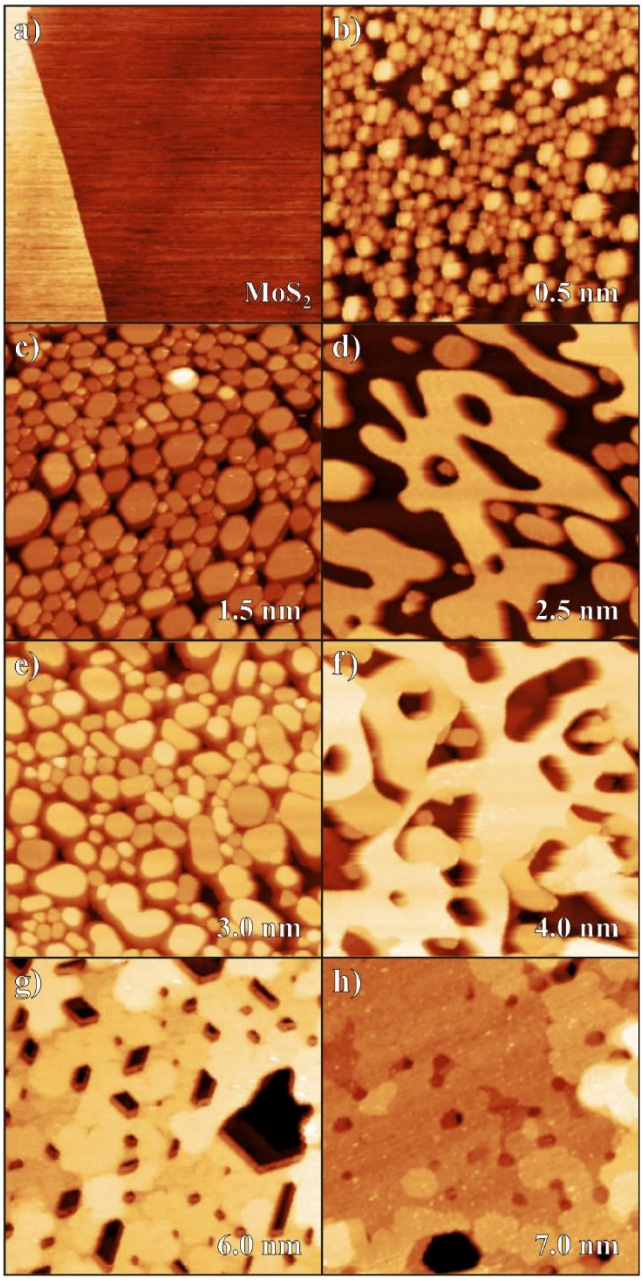

Figure 1. STM topography images. (a) 1x1 µm square image of a clean MoS_2 surface. (b-h) 200x200 nm square images at indicated Au coverages, after deposition and subsequent annealing to 650K.

We have recently discovered that quantum processes dominate the growth of gold and silver films on the layered semiconductor MoS_2.[5, 6] Quantized growth proceeds with little regard for lattice matching and at elevated temperatures compatible with standard device fabrication. The resulting metal films show highly stable, discrete nanostructures with preferential sizes correlated to the electronic structure of the metal. In this work, we explore the quantum growth of Au on MoS_2 in order to achieve an atomically uniform Au(111) film without obvious signs of the granular structure seen on ultra-flat Au films grown on other substrates.[25, 27]

When grown on MoS_2, atomically flat Au(111) nanostructures spontaneously form over a wide coverage range. Figure 1 shows a selection of STM scans for coverage ranges up to 7.0 nm. Figure 1a exemplifies the MoS_2 surface before deposition. The MoS_2 surfaces are very flat, in this case showing a single molecular step edge over a 1µm square scan. For coverages below 2

nm, Au formed atomically flat, discrete nanostructures with geometric facets. As expected,[30-32] there is a 60º symmetry to the nanostructure edges showing their orientation is coupled to the MoS_2 substrate.

Between 2.5 and 4.0 nm of coverage the situation is more complex. Samples exhibit both discrete, faceted nanostructures as well as larger structures with much smoother boundaries. The distribution between these faceted nanostructures and the larger structures varies with thickness, with a 2.5 nm samples showing a combination of the two features, 3.0 nm dominated by the geometric nanostructures, and the 4.0 nm sample dominated by the larger features. Such variety indicates the resultant structures could be very sensitive to subtle differences in growth conditions or initial nucleation that might be difficult to account for in this limited coverage range. The geometric facets in the smaller gold nanostructures correlate with the Au electronic structure and arise from quantum effects.[5] The lateral sizes of the other features are too large for quantum size effects to dominate, leading to the smoother outlines. In both cases, the atomically flat surfaces indicate there is dominate quantum confinement in the surface normal direction.

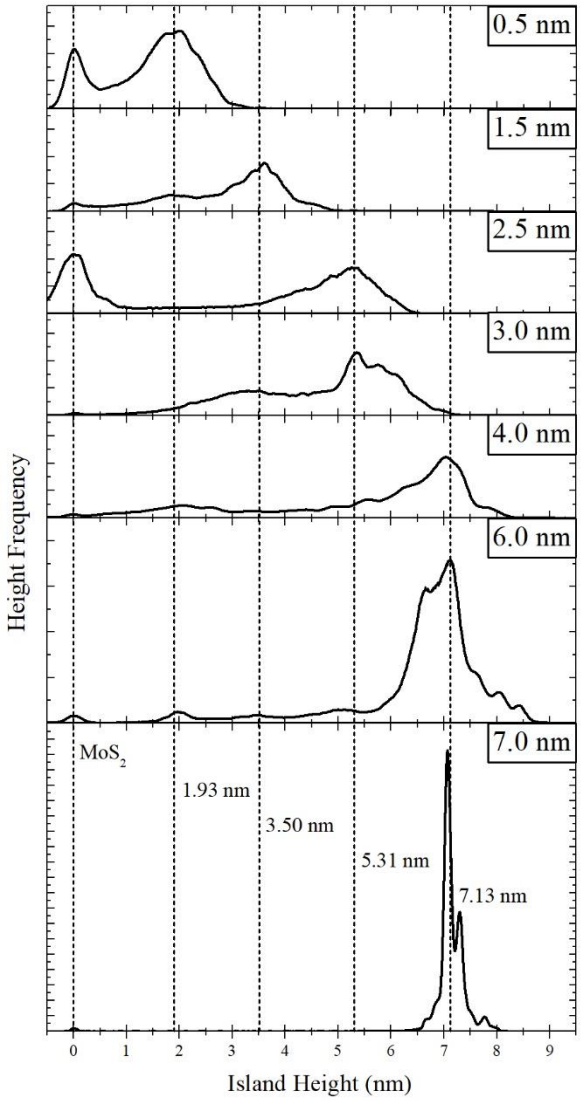

Figure 2. Histograms of height measurements taken from Figs. 1b-h. Vertical dashed lines indicate the location of the MoS_2 surface and preferred heights found at different coverages.

For coverages above 4 nm, the Au nanostructures agglomerate to form a continuous network covering most of the surface, although pinholes extending down to the MoS_2 surface still exist even at the 7.0 nm coverage. The surface is composed of steps and terraces that are atomically

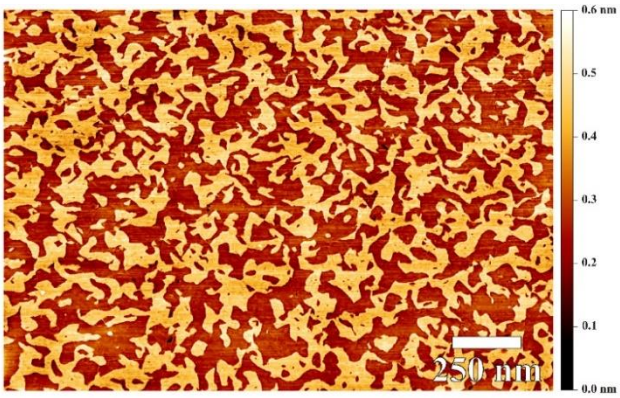

Figure 3. High Contrast STM topgraphy taken from Au covered MoS_2 surface with 8.5 nm coverage annealed to 650 K. The film is highly uniform with bright areas only one atom thicker than darker regions.

flat. At these larger coverages, the empty spaces show faceting similar to discrete Au nanostructures seen at lower coverages.

Examining histograms of the sample height measured by STM (Fig. 2) shows how strong the preference for specific heights is in this system. These results show the preferred heights follow an average interval of 1.8 nm, which corresponds to the Au(111) surface Fermi wavelength in agreement with a previous study.[5] It has been shown that bulk and surface electrons have nearly identical Fermi wavelengths for Au thicknesses well over 100 nm,[33] which would explain why the 1.8 nm interval persists up to a film thickness of 7.1 nm. For Au films of these thicknesses, the bulk and surface states have been shown to have nearly the same Fermi surface wavelengths In each case, care was taken to evaluate the location of the MoS_2 surface to provide accurate measurements. This height interval corresponds to 7.5 atomic layers, resulting in the intervals of 7 or 8 atomic layers height seen in the histograms.

The measurements clearly show the preferred height at 7.1 nm has unique features. It is an extremely stable state and the last preferred height seen in the system. For lower coverages, the gold forms structures with preferred heights significantly larger than the actual coverage. This pattern ends when reaching 4 nm coverage. For coverages between 4.0, 6.0 and 7.0 nm, the samples all show a preferred height of 7.1 nm, with no signs of the next expected preferred height at 8.9 nm. This is consistent with the upper limit for lateral quantization effects, which dropped off dramatically above 6 nm and were weak at best above 8 nm.[5] It appears the Au electrons lose phase coeherence at length scales between 7 and 9 nm. Furthermore, the histogram peak narrows continuously as coverage is increased in this range. At the 7.0 nm coverage, the 7.1 nm peak, and the peak at the next atomic layer, have by far the smallest width. Therefore, the 7.1 nm height is the most stable in this coverage range.

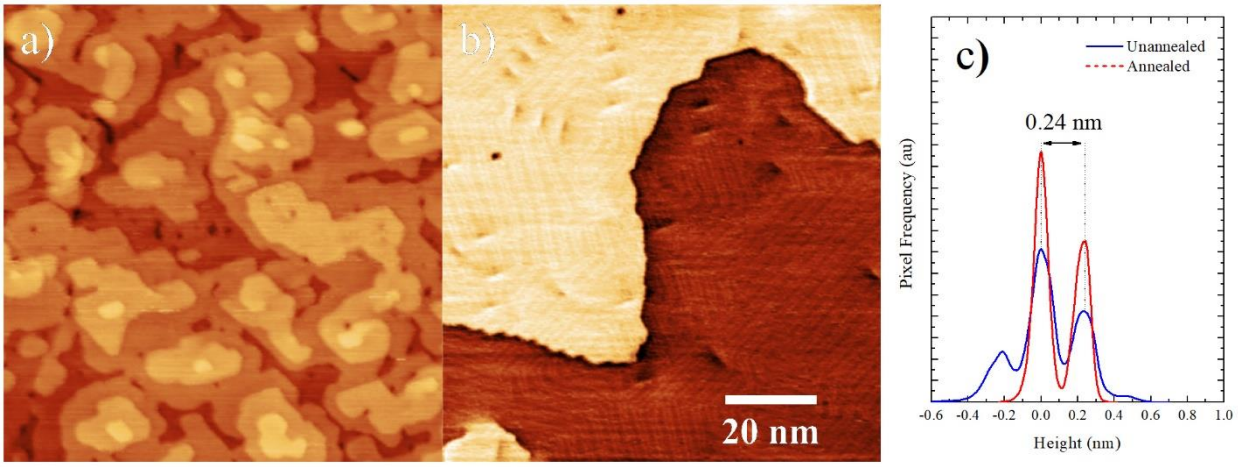

Figure 4: (a,b) STM Topgraphy taken from 8.5 nm Au coverage on MoS_2. (a) and (b) have the same lateral scale. STM measurements taken after room temperature depostiion (a) and subsequent annealing to 650K (b). (c) Histogram of heights measured in the samples shown in images (a) and (b), but utilizing a larger sample area. Relative heights are taken with respect to the most common Au film thickness, which is set to zero relative height.

For coverages larger than the preferred height of 7.1 nm, the system shifts to layer by layer growth with atomic flatness. Figure 3 shows a relatively large scale and high contrast STM image in this regime. As for all coverages exceeding the final preferred height of 7.1 nm, the gold film is continuous and covers the entire MoS_2 surface. The surface is extremely uniform in height, with an RMS surface roughness < 50 pm. The entire film consists essentially of a base layer with some regions one atom thicker over the entire 3 μm^2 surface area. Interestingly, only step sizes corresponding to single Au atoms can be found. It is surprising to not see evidence for 0.6 nm MoS_2 step edges buried beneath the film, indicating that this film appears to be more atomically flat than the MoS_2 surface itself. These results were consistent across all samples measured, which included coverages up to 20 nm thickness.

The quality of the Au surface is further confirmed in Figure 4, which shows the effects of annealing on samples in the layer by layer coverage regime. Histograms are also displayed, although only relative heights can be determined as there are no longer any pinhole defects reaching the MoS_2 surface. Before annealing, the system is dominated by three individual atomic heights. The surface shows rounded plateaus covering relatively small lateral areas.[34] After annealing, the plateaus are much larger, and the surface only has two distinct atomic layers. Regardless of annealing, the plateaus show faceting at step edges as expected for the Au(111)

surface. The quality of the annealed surface is impeccable for such a simple growth process. Herringbone structures associated with Au(111) surfaces of the highest quality are visible on both atomic levels.[35] The herringbone features are aligned with both step edges and subatomic depressions found on the surface of both layers. It is not clear if these subatomic features, measuring about 0.2 Å, are electronic or physical in nature. The herringbone features were not seen at lower coverages. While lower coverage plateaus are atomically flat, their lateral extent is likely insufficient to support the formation of such superstructures.

A combination of weak bonding to the van der Waals surface and strong electronic confinement effects arising from the abrupt interface with the semiconducting MoS_2 enable quantum effects to dominate the initial growth of Au on MoS_2.[5] This results in features with discrete sizes, correlated with the opening of electronic energy gaps at the Fermi level. These quantum size effects result in structures with relatively low energies and preferred heights (Fig. 2) and dominate the growth process to form nanostructures with atomically flat surfaces until a highly stable height is reached at a 7.1 nm. For higher coverages beyond 7.1 nm, the gold grows epitaxially at room temperature to form atomically flat and uniform films. The surface is improved by annealing to form a surface exhibiting only two atomic heights. These uniform films surprisingly show minimal strain given the 8% lattice mismatch between Au and MoS_2. Normally this level of strain would completely inhibit epitaxial growth. The bonding at the interface must be strong enough for the films to be oriented, but weak enough so the Au atoms have high surface mobility to reach equilibrium states and allow quantum growth effects to overcome the large lattice mismatch. For the Au/MoS2 system, the interface appears to be sufficiently balanced for epitaxial growth with minimal impact from strain.

It is unusual for quantum growth effects to influence structures as large as 7.1 nm, roughly 30 atomic layers. In other systems which exhibit such quantum size effects, the influence of electronic growth weakens with increased coverage and rarely persist beyond 20 atomic layers.[36] Here we see the opposite effect, where the most energetically preferred height is actually the largest. This length scale also correlates well with the lateral confinement effects seen at low coverages in the Au(111)/MoS_2 system.[5] Another novel aspect of this system is that the preferred height interval corresponds to nearly 8 atomic layers. This is far greater than the bilayer oscillations typically seen in quantum growth systems.[36,37] These factors, coupled with the

persistence of electronic growth at high temperatures, show the electronic energy scales are relatively large in this system.

At all coverages, the Au/MoS_2 are highly inert. There were no signs of degradation over weeks of measurement in vacuum or even upon exposure to ambient conditions. The inherent stability of gold is enhanced by the formation of electronic energy gaps at preferential heights, reducing the concentration of high energy electrons which take part in chemical bonding. This would reduce the reactivity of samples in the lower coverage regime, where discrete nanostructures have very large surface areas.

Conclusions

We have achieved a high quality, atomically flat Au(111) surface after depositing only 8.5 nm of Au. These films are uniform over all areas measured, with no signs of grain boundaries or pinhole defects even in scans taken over several square microns. With a surface roughness less than 50 pm, this represents a great advance over current Au thin film technologies, requires far less Au deposition, and lacks pinholes, grain boundaries, and other major defects usually found in flat Au film substrates [25-27]. In the layer-by-layer regime, this Au/MoS_2 system approaches single crystal Au(111) surfaces in terms of quality, but at far less cost. The samples also show the long-term stability necessary for applications as substrates. This discovery could yield far superior platforms for applications such as self-assembled monolayers[7]. Gold film substrates are a standard template for such studies, and the achievement of a stable, atomically flat surface will enable higher resolution measurements with far less inconsistencies.

This work represents a new route for atomic-scale control in self-assembled nanostructures. The quantum processes are robust to thirty atomic layers, after which growth proceeds in a layer-by-layer fashion to form an atomically flat, high quality Au(111) surface. This process is stable to temperatures exceeding 650K, and therefore compatible with standard electronic device fabrication processes. The electronic energy scales are competitive with standard growth parameters related to bonding, surface energy, and growth kinetics. Further, the ability to form a stable atomically defined Au(111) surface with simple processing will make ultra-flat Au films accessible as substrates for a wide variety of scientific investigations.

Acknowledgements

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References

1. Zhang, Z.; Niu, Q.; Shih, C.-K., ``Electronic Growth'' of Metallic Overlayers on Semiconductor Substrates. *Physical Review Letters* **1998,** *80* (24), 5381-5384.

2. Yeh, V.; Berbil-Bautista, L.; Wang, C. Z.; Ho, K. M.; Tringides, M. C., Role of the Metal/Semiconductor Interface in Quantum Size Effects: Pb/Si(111). *Physical Review Letters* **2000,** *85* (24), 5158-5161.

3. Su, W. B.; Chang, S. H.; Jian, W. B.; Chang, C. S.; Chen, L. J.; Tsong, T. T., Correlation between Quantized Electronic States and Oscillatory Thickness Relaxations of 2D Pb Islands on Si(111)-(7×7) Surfaces. *Physical Review Letters* **2001,** *86* (22), 5116-5119.

4. Han, Y.; Ünal, B.; Jing, D.; Qin, F.; Jenks, C. J.; Liu, D.-J.; Thiel, P. A.; Evans, J. W., Formation and coarsening of Ag(110) bilayer islands on NiAl(110): STM analysis and atomistic lattice-gas modeling. *Physical Review B* **2010,** *81* (11), 115462.

5. Kidd, T. E.; Weber, J.; Holzapfel, R.; Doore, K.; Stollenwerk, A. J., Three-dimensional quantum size effects on the growth of Au islands on MoS2. *Applied Physics Letters* **2018,** *113* (19), 191603.

6. Kidd, T. E.; O'Leary, E.; Anderson, A.; Scott, S.; Stollenwerk, A. J., Self-assembled Ag(111) nanostructures induced by Fermi surface nesting. *Physical Review B* **2019,** *100* (23), 235447.

7. Ulman, A., Formation and Structure of Self-Assembled Monolayers. *Chemical Reviews* **1996,** *96* (4), 1533-1554.

8. Lee, H.; Deshmukh, S.; Wen, J.; Costa, V. Z.; Schuder, J. S.; Sanchez, M.; Ichimura, A. S.; Pop, E.; Wang, B.; Newaz, A. K. M., Layer-Dependent Interfacial Transport and

Optoelectrical Properties of MoS2 on Ultraflat Metals. *ACS Applied Materials & Interfaces* **2019,** *11* (34), 31543-31550.

9. Gupta, P.; Loos, K.; Korniakov, A.; Spagnoli, C.; Cowman, M.; Ulman, A., Facile Route to Ultraflat SAM-Protected Gold Surfaces by "Amphiphile Splitting". *Angewandte Chemie International Edition* **2004,** *43* (4), 520-523.

10. Fang, N.; Liu, Z.; Yen, T. J.; Zhang, X., Experimental study of transmission enhancement of evanescent waves through silver films assisted by surface plasmon excitation. *Applied Physics A* **2005,** *80* (6), 1315-1325.

11. Vogel, N.; Zieleniecki, J.; Köper, I., As flat as it gets: ultrasmooth surfaces from template-stripping procedures. *Nanoscale* **2012,** *4* (13), 3820-3832.

12. Hummon, M. R.; Stollenwerk, A. J.; Narayanamurti, V.; Anikeeva, P. O.; Panzer, M. J.; Wood, V.; Bulović, V., Measuring charge trap occupation and energy level in CdSe/ZnS quantum dots using a scanning tunneling microscope. *Physical Review B* **2010,** *81* (11), 115439.

13. Lu, X.; Grobis, M.; Khoo, K. H.; Louie, S. G.; Crommie, M. F., Charge transfer and screening in individual C60 molecules on metal substrates: A scanning tunneling spectroscopy and theoretical study. *Physical Review B* **2004,** *70* (11), 115418.

14. Nie, S.; Bartelt, N. C.; Wofford, J. M.; Dubon, O. D.; McCarty, K. F.; Thürmer, K., Scanning tunneling microscopy study of graphene on Au(111): Growth mechanisms and substrate interactions. *Physical Review B* **2012,** *85* (20), 205406.

15. Schouteden, K.; Galvanetto, N.; Wang, C. D.; Li, Z.; Van Haesendonck, C., Scanning probe microscopy study of chemical vapor deposition grown graphene transferred to Au(111). *Carbon* **2015,** *95*, 318-322.

16. Süle, P.; Szendrő, M.; Magda, G. Z.; Hwang, C.; Tapasztó, L., Nanomesh-Type Graphene Superlattice on Au(111) Substrate. *Nano Letters* **2015,** *15* (12), 8295-8299.

17. Oncins, G.; Vericat, C.; Sanz, F., Mechanical properties of alkanethiol monolayers studied by force spectroscopy. *The Journal of Chemical Physics* **2008,** *128* (4), 044701.

18. Kawai, S.; Koch, M.; Gnecco, E.; Sadeghi, A.; Pawlak, R.; Glatzel, T.; Schwarz, J.; Goedecker, S.; Hecht, S.; Baratoff, A.; Grill, L.; Meyer, E., Quantifying the atomic-level

mechanics of single long physisorbed molecular chains. *Proceedings of the National Academy of Sciences of the United States of America* **2014,** *111* (11), 3968-3972.

19. Ikeda, K.; Fujimoto, N.; Uehara, H.; Uosaki, K., Raman scattering of aryl isocyanide monolayers on atomically flat Au(111) single crystal surfaces enhanced by gap-mode plasmon excitation. *Chemical Physics Letters* **2008,** *460* (1), 205-208.

20. Lelaidier, T.; Lünskens, T.; von Weber, A.; Leoni, T.; Ranguis, A.; D'Aléo, A.; Fages, F.; Kartouzian, A.; Becker, C.; Heiz, U., Optical and morphological properties of thin films of bis-pyrenyl π-conjugated molecules. *Physical Chemistry Chemical Physics* **2016,** *18* (7), 5299-5305.

21. Nuzzo, R. G.; Allara, D. L., Adsorption of bifunctional organic disulfides on gold surfaces. *Journal of the American Chemical Society* **1983,** *105* (13), 4481-4483.

22. Love, J. C.; Estroff, L. A.; Kriebel, J. K.; Nuzzo, R. G.; Whitesides, G. M., Self-Assembled Monolayers of Thiolates on Metals as a Form of Nanotechnology. *Chemical Reviews* **2005,** *105* (4), 1103-1170.

23. Miyeon, L.; Changjun, P.; Hyoban, L.; Hongki, K.; Sang Youl, K.; Insik, I.; Bongsoo, K., Remarkably enhanced adhesion of coherently aligned catechol-terminated molecules on ultraclean ultraflat gold nanoplates. *Nanotechnology* **2016,** *27* (47), 475705.

24. Hell, M. G.; Senkovskiy, B. V.; Fedorov, A. V.; Nefedov, A.; Wöll, C.; Grüneis, A., Facile preparation of Au(111)/mica substrates for high-quality graphene nanoribbon synthesis. *Physica Status Solidi (b)* **2016,** *253* (12), 2362-2365.

25. Lüssem, B.; Karthäuser, S.; Haselier, H.; Waser, R., The origin of faceting of ultraflat gold films epitaxially grown on mica. *Applied Surface Science* **2005,** *249* (1), 197-202.

26. Nogues, C.; Wanunu, M., A rapid approach to reproducible, atomically flat gold films on mica. *Surface Science* **2004,** *573* (3), L383-L389.

27. Hegner, M.; Wagner, P.; Semenza, G., Ultralarge atomically flat template-stripped Au surfaces for scanning probe microscopy. *Surface Science* **1993,** *291* (1), 39-46.

28. Man, K. L.; Qiu, Z. Q.; Altman, M. S., Quantum size effect driven thermal decomposition of Ag films on Fe(100) in the presence of pinhole-growth morphological defects. *Physical Review B* **2010,** *81* (4), 045426.

29. Miyazaki, M.; Hirayama, H., Thickness- and deposition temperature-dependent morphological change in electronic growth of ultra-thin Ag films on Si(111) substrates. *Surface Science* **2008,** *602* (1), 276-282.

30. Darby, T. P.; Wayman, C. M., Growth of gold films on air- and vacuum-cleaved molybdenite. *Physica Status Solidi (a)* **1974,** *25* (2), 585-590.

31. Honjo, G.; Takayanagi, K.; Kobayashi, K.; Yagi, K., On cluster mobilities in nucleation and growth processes of epitaxial thin films. *Physica Status Solidi (a)* **1979,** *55* (2), 353-367.

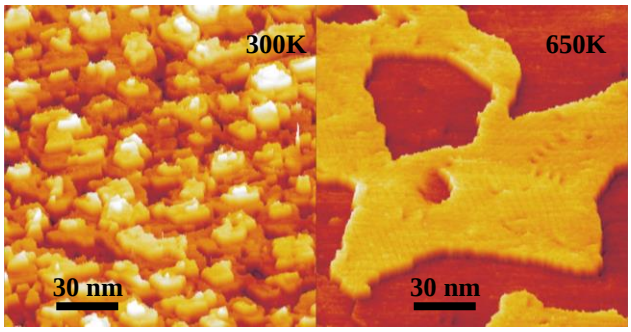
32. Nagashima, S.; Otsuka, I., Surface topography of epitaxial Au(111) films deposited on MoS2. *Journal of Crystal Growth* **1995,** *146* (1), 266-270.

33. Schouteden,K.; Lievens, P.; Van Haesendonck, C. Fourier-transform scanning tunneling microscopy investigations of the energy versus wave vector dispersion of electrons at the Au(111) surface. *Physical Review B* **2009**, *79* (19), 195409.

34. Cook, M.; Palandech, R.; Doore, K.; Ye, Z.; Ye, G.; He, R.; Stollenwerk, A. J., Influence of interface coupling on the electronic properties of the Au/MoS2 junction. *Physical Review B* **2015,** *92* (20), 201302.

35. Walen, H.; Liu, D.-J.; Oh, J.; Lim, H.; Evans, J. W.; Kim, Y.; Thiel, P. A., Self-organization of S adatoms on Au(111): √3R30° rows at low coverage. *The Journal of Chemical Physics* **2015,** *143* (1), 014704.

36. Otero, R.; Vázquez de Parga, A. L.; Miranda, R., Observation of preferred heights in Pb nanoislands: A quantum size effect. *Physical Review B* **2002,** *66* (11), 115401.

37. Goswami, D. K.; Bhattacharjee, K.; Satpati, B.; Roy, S.; Satyam, P. V.; Dev, B. N., Preferential heights in the growth of Ag islands on Si(111)-(7×7) surfaces. *Surface Science* **2007,** *601* (3), 603-608.

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