Electronic Growth

We have been considering growth based on the constraints of surface/interface energetics and supersaturation.

In 1996, a discovery was made of a *new* kind of growth, unlike the 3 types described already (2-D, 2-D/3-D, and 3D).

"**Formation of atomically flat silver films on GaAs with a ''silver mean'' quasi periodicity"**, Smith AR, Chao KJ, Niu Q, Shih CK, SCIENCE 273 (5272): 226-228 JUL 12 1996.

This new growth represented a method of producing 2-D (atomically flat) metallic films on a semiconductor surface. There were several steps to the "growth procedure".

New Growth Procedure for flat 2-D films:

1. prepare the clean semiconductor substrate surface
2. cool the substrate down to ~150K (-123 ºC)
3. deposit a specific amount of metal atoms
4. slowly warm the substrate up to room temperature

Some points about the method

- specific example shown was for silver on gallium arsenide [Ag on GaAs(110)]
- for Ag on GaAs(110), previous studies had shown that if deposition of Ag is done at 300K (RT), the film will be 3D islands (Trafas et al, 1991)
- for Ag on GaAs(110), quantum size effects had also been demonstrated (Evans et al., 1993)
- until the paper by Smith et al., such a growth method was unknown

Ag on GaAs(110) studied by STM by Trafas et al. (1991)

Ag was reported to form 3 dimensional structures:

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Scanning tunneling microscopy of Ag growth on GaAs(110) at 300 K: From clusters to crystallites

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Scanning-tunneling-microscopy (STM) studies of Ag overlayer growth on GaAs(110) at 300 K show cluster nucleation at low coverage followed by conversion to nanocrystallites with distinct facets. Clusters formed by depositions below ~0.5 monolayer (ML) Ag exhibit no apparent preferential substrate orientation, and individual atoms within the clusters cannot be resolved. These are three-dimensional (3D) clusters, as shown by calculations of cluster volumes and areas based on the STM images, and they contain up to ~250 atoms. Continued deposition yields new small clusters in addition to the growth of existing clusters and the coalescing of clusters in close proximity. By ~5 ML deposition the Ag structures exhibit crystalline order and expose {111} facets. The evolution from clusters to crystallites also involves a preferential orientation so that [$1\bar{1}0$] of Ag is parallel to [$1\bar{1}0$] of GaAs(110) and the Ag overlayer (111) plane is tilted 25° around the [$1\bar{1}0$] direction of GaAs(110). The overlayer derived from these 3D crystallites is then highly irregular, and contact with the partially relaxed GaAs(110) surface is achieved through regularly stepped Ag(110) planes. These results demonstrate weak substrate interaction and cooperative Ag rearrangement to minimize surface energies, even at 300 K.

Initial Deposition of ¼ ML of Ag on GaAs at 300K

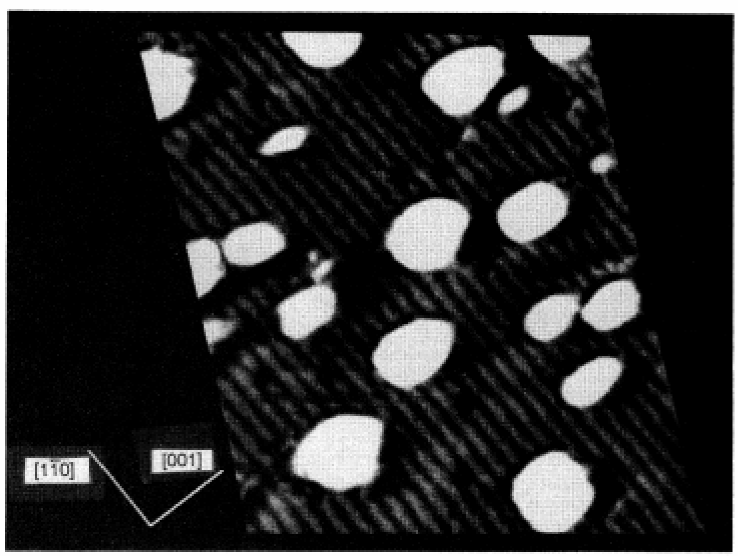


FIG. 1. STM image of GaAs(110) following evaporation of 0.25 ML of Ag at 300 K for an area of 120×120 Å^2. The image was acquired with a sample voltage of −1.9 V and corresponds to imaging As atoms. Dark depressions represent surface defects, whereas the bright areas reflect 3D clusters of Ag. The typical volume of these clusters is ~150–2500 Å^3.

- taken from Trafas et al., Phys. Rev. B 43(17), 14107 (1991).

STM studies of the Ag islands as a function of the coverage:

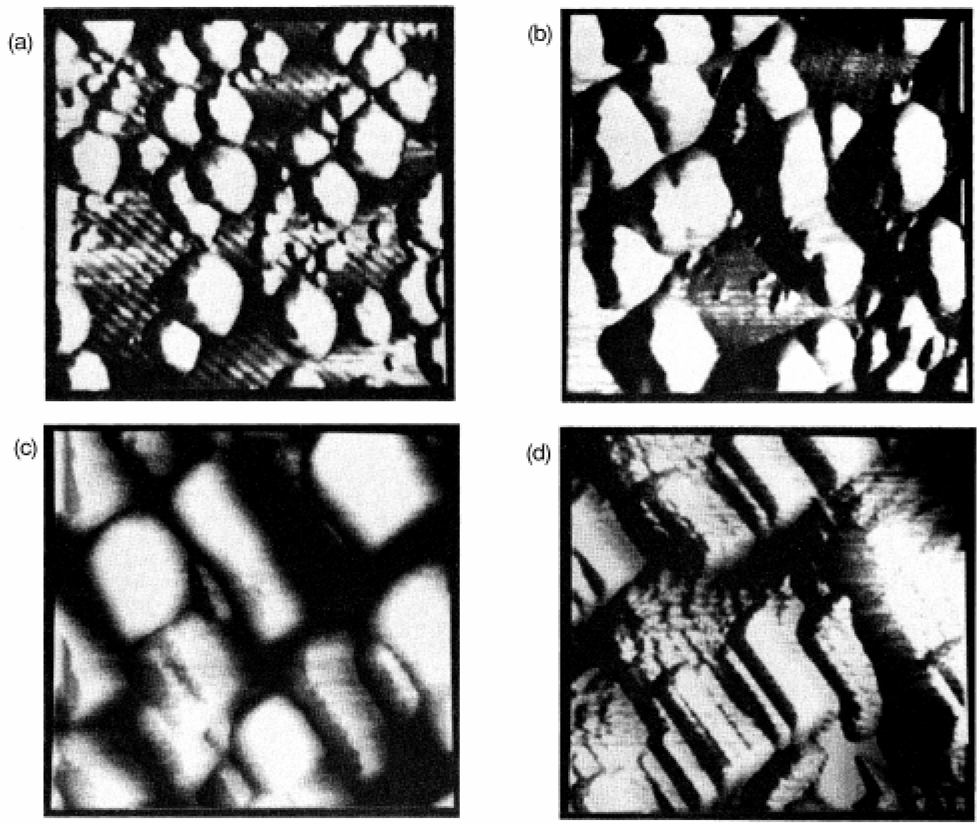
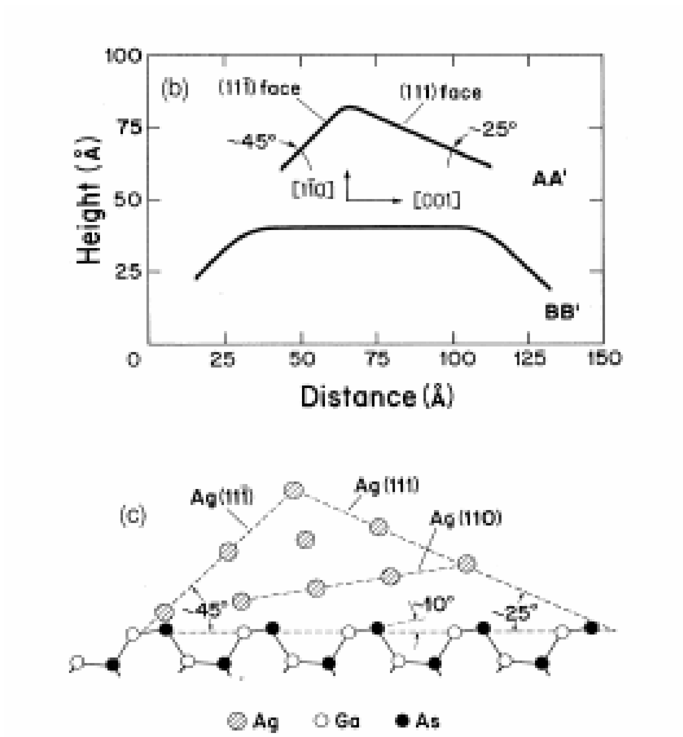


FIG. 2. (a)–(d) STM images of Ag overlayer growth by atom deposition onto GaAs(110) at 300 K for coverages of (a) 0.5, (b) 1.5, (c) 5, and (d) 10 ML of Ag on GaAs(110). The areas imaged are 220×220, 320×320, 425×425, and 425×425 Å^2, respectively. Images (a) and (b) were obtained with a sample bias of −2.5 V and a tunneling current of 0.1 nA. Images (c) and (d) were obtained with −0.8 V and 1 nA to enhance the contrast of the metal surface. The gray scale in these images is computed according to a surface directional derivative, corresponding to illumination from a point in the upper-right corner of each image. Ag clustering is apparent in (a) and (b). Faceting and the transition to crystallites is evident in (c) and (d) where the long dimension is along [1$\bar{1}$0] and the short dimension is along [001].

- taken from Trafas et al., Phys. Rev. B 43(17), 14107 (1991).

Ag on GaAs(110) Study
Trafas et al., Phys. Rev. B 43(17), 14107 (1991).

Trafas et al. go on to form a model for the crystallites consisting of 3-D faceted structures



- taken from Fig. 4, Trafas et al., Phys. Rev. B 43(17), 14107 (1991).

1993 Study Reporting Quantum Size Effects in Ag on GaAs(110)

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Observation of Quantum Size Effects in Photoemission from Ag Islands on GaAs(110)

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(Received 14 December 1992)

A set of extra peaks, which dominate the region of the silver *s-p* band, are observed in angle-resolved photoemission from Ag islands formed on GaAs(110) by low temperature deposition and annealing to room temperature. The thickness dependence of peak spacing demonstrates that the new peaks originate from wave vector quantization due to electron confinement. The overall features of the spectra are reproduced within a model based on a superposition of emission from a distribution of island sizes, and are interpreted as quantum size effects in these small metal "quantum dots."

PACS numbers: 73.20.Dx, 73.61.At, 79.60.Bm

- Evans and Horn reported a set of "extra peaks" which dominated the region of the silver s-p band

- They used the method of low-temperature deposition and annealing to room temperature

- Results indicated quantum size effects

- A model was formed based on a distribution of island sizes

- In the end, the interpretation had to be changed

Evans and Horn work (1993) on Ag on GaAs(110)

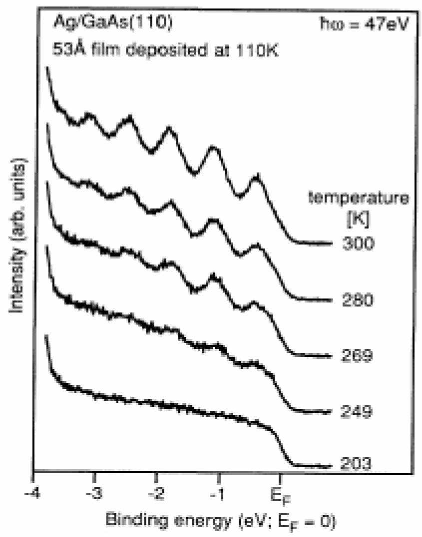

FIG. 2. Valence photoelectron spectra of a 53 Å silver layer on GaAs(110), deposited at 100 K, for several annealing temperatures. Photon energy was 47 eV. Slight difference in background as compared with spectra of Fig. 3 are caused by lower instrumental resolution in this set of spectra.

- Evans et al., Phys. Rev. Lett. 70(22), 3483 (1993)

What can be seen by the above:

- uniformly spaced peaks appear at as low as 249 K
- by 300K, the peaks are well developed
- from 203 to 300K, the peak structure evolves continuously
- none of the periodic peak features was ever observed by the authors in films grown at 300K

The dependence of the features on the thickness of Ag deposited

Evans and Horn PRL

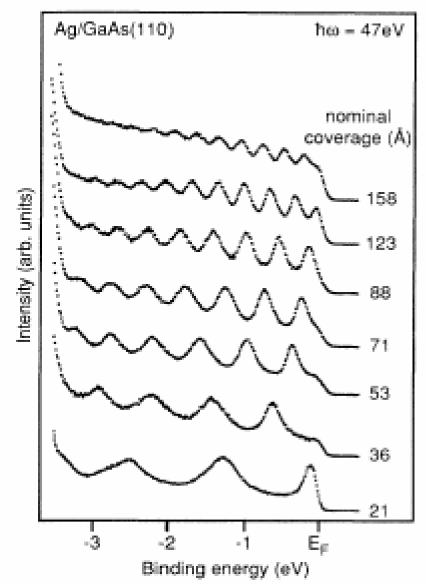

FIG. 3. Valence photoelectron spectra of seven Ag layers of different thickness as indicated, prepared by deposition at 100 K and subsequent annealing to room temperature. Spectra were recorded at 25° polar angle with respect to the surface normal along the [011] azimuth of the GaAs(110) surface.

- Evans et al., Phys. Rev. Lett. 70(22), 3483 (1993)

What can be seen in the above figure:

- periodic peaks seen at coverages as low as 21 Angstrom
- periodic peaks seen also at coverages as high as 158 Ang.
- periodic peak spacing decreases for increasing coverage
- features never seen in films deposited at RT (300K)

Interpretation: the behavior suggested quantum size effects:

- size-dependent quantum confined states: smaller confined volume corresponds to more widely-spaced energy levels; larger confined volume corresponds to more narrowly-spaced energy levels

- results suggested that the grown film consisted of uniform-sized Ag 3-D islands

- a uniform size distribution would mean that the quantum states from neighboring islands would become coherent

- in the end, a Different interpretation was necessary

Motivated by the intriguing results of the above two papers, Smith et al. studied the LT-deposition/annealing process for Ag/GaAs(110), this time using STM. This study would ultimately lead to a reshaping of thinking concerning morphology stabilization.