

## Discovery of thin flat film formation: Ag on GaAs(110)

Ag on GaAs which had shown the quantum size effects (QSE's) using the low-T deposition and annealing method was an ideal system for further study.

Goals of the study (1994-95):

1. investigate the novel growth of uniform size distribution of Ag islands on GaAs(110)
2. investigate the QSE effects using scanning tunneling spectroscopy

With these goals in mind, the experiment was performed.

The Results:

No Quantum Dots or 3-D islands were found!!!

The surface was instead atomically flat, with pinholes down to the substrate.

### **Formation of Atomically Flat Silver Films on GaAs with a "Silver Mean" Quasi Periodicity**

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A flat epitaxial silver film on a gallium arsenide [GaAs(110)] surface was synthesized in a two-step process. Deposition of a critical thickness of silver at low temperature led to the formation of a dense nanocluster film. Upon annealing, all atoms rearranged themselves into an atomically flat film. This silver film has a close-packed (111) structure modulated by a "silver mean" quasi-periodic sequence. The ability to grow such epitaxial overlayers of metals on semiconductors enables the testing of theoretical models and provides a connection between metal and semiconductor technologies.

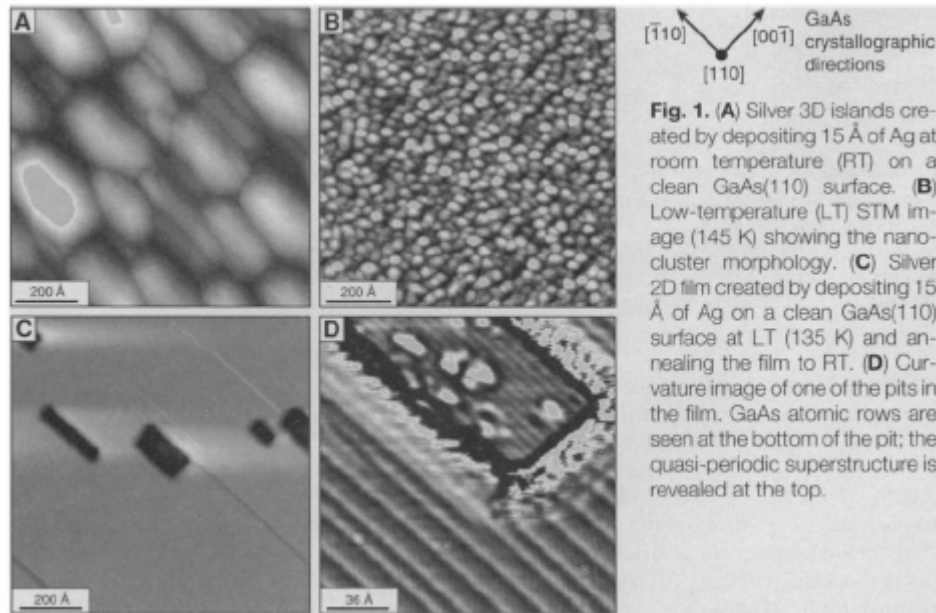
- *Science* 273, 226 (1996)

The finding was a complete revolution of the then-understood phenomena of surface growth, which is that it was determined by:

- surface energy/enthalpy
- surface kinetics
- other details such as diffusion barriers, steps, defects, etc.

The new result showed that those processes are not the only important parameters affecting the mode of growth

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What occurred during the growth procedure?

1. At low-T, a nanocluster morphology was formed by the deposition of Ag on the surface of GaAs(110)
2. As the film warmed up, the nanoclusters began to “melt” into each other and the final flat film began to form
3. At RT, the film formed a certain “critical” thickness (about 15 Å) and where there was not enough to go around, pits were formed.

Can any of this be understood in terms of the capillary model?

What we already know from the capillary model is that:

- a) at high supersaturation conditions, the nucleation rate of islands is larger than at low supersaturation conditions
- b) at high supersaturation conditions, the critical island size is smaller than at low supersaturation conditions

Therefore, we can understand that the low-temperature growth step should result in a high nucleation rate of small nuclei

This is observed in the low-T STM image of the surface as-deposited at low-T

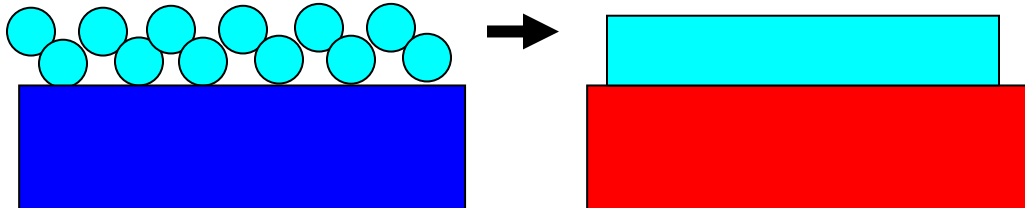
Can we understand how the surface should evolve as the temperature is increased?

What we can say is that at higher temperature:

- 1) the critical island size is larger
- 2) the previously-stable clusters become sub-critical
- 3) major mass diffusion is then possible

In low-T STM observations, as the sample warms up, the cluster nuclei begin to “melt” into each other, to become a smooth, flat film

- kinetic limitations prevent the formation of larger stable islands
- a preferred thickness of the film is observed
- something results in stability for the flat film compared to 3-D island formation



A critical thickness is found to occur experimentally:

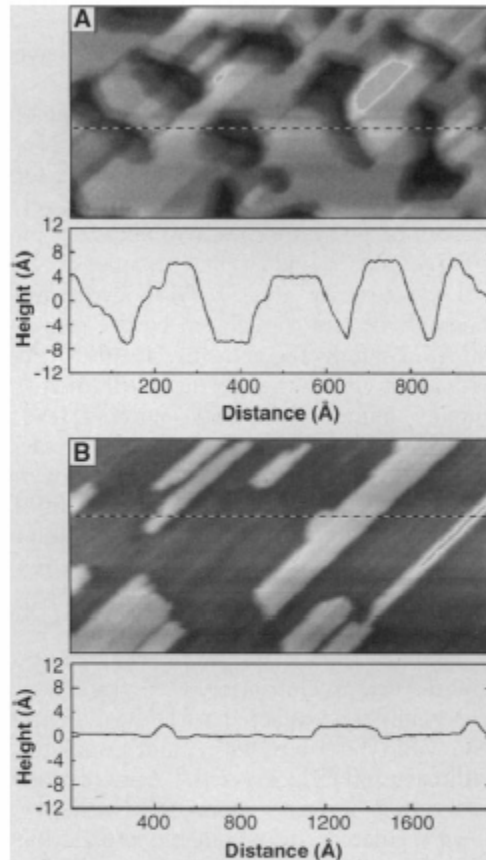
Too little Ag deposited → voids in between the flat-topped ‘mesas’

More than enough Ag deposited → excess Ag monolayer islands on top

Questions to be addressed:

- what is the cause of this flat film?
- Why is it stable?
- Does this occur in other systems (i.e. Pb on Si or In on GaP?)

Ag on GaAs(110): dependence of the structure on amount of Ag deposited



**Fig. 2.** (A) Morphology of film created by depositing 7.5 Å of Ag at LT and annealing to RT. Two characteristic mesa heights are shown in the line profile, which was taken at the dotted line in the STM image. (B) Flat Ag film created by depositing 22.5 Å of Ag at LT and annealing to RT. As shown in the line profile, 2D islands with single-monolayer height are scattered about the surface.

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The questions concerning why this works must be answered by theory.

This led to another important paper published in Physical Review Letters