Local Characterization of Electrical Transport in Microcrystalline Germanium Thin Films by Atomic Force Microscopy using a conducting probe

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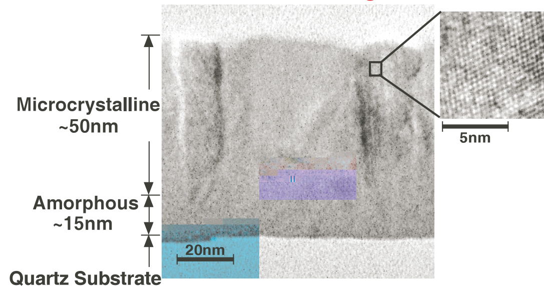
Background

Microcrystalline Thin Film

TEM Images

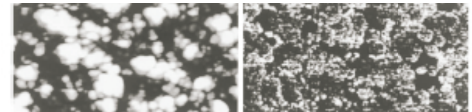


Film usually have a layered structure consisting of amorphous and microcrystalline layers.

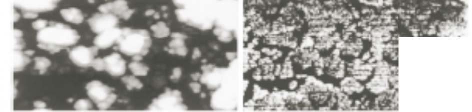
Characterization of μc-Si:H on Metals and ITO by AFM with a conducting catilever

Topographic Images   Current Images

Thickness 300 nm



Thickness 600 nm

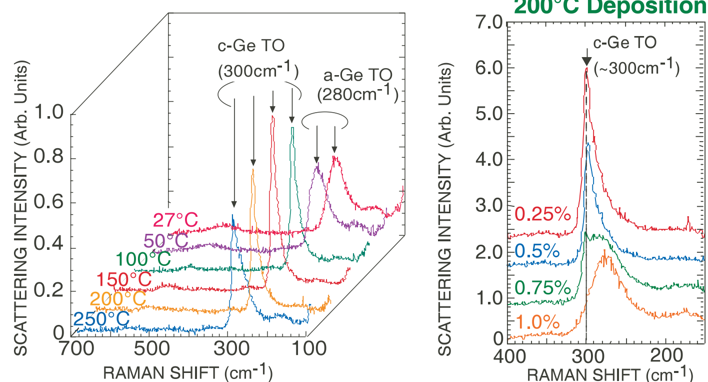


*A. Fejfar, B. Rezek, P. Knapek, J. Stuchlik and J. Kocka. J. Non-Cryst. Solids **266-269** (2000) 309.*

- The origin of the contrast in local current measurement is still a matter of research.
- No report the very early stages of microcrystallization have not been characterized.

Previous Work

Ge:H Film

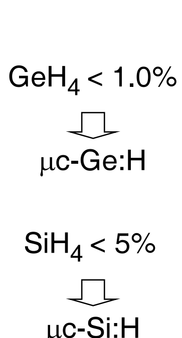


Substrate Temperature Dependence

200°C Deposition

SCATTERING INTENSITY (Arb. Units) 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0; RAMAN SHIFT (cm^{-1}) 400 300 200; c-Ge TO (~300cm^{-1}); 0.25%, 0.5%, 0.75%, 1.0%

GeH_4 Concentration Dependence



14th Symp. on Plasma Science for Materials, H.Takahashi (Tokyo, June, 2001)

This Work

Surface Morphology・ Local Electric Transport through the films Simultaneously by a Conducting AFM Probe

The Origin of the Local Contrast

Experiment

μc-Ge:H films deposition

- Substrate : n^+-Si(100), p-Si(100), Cr / p-Si(100) and SiO_2
- Temperature: 150° C
- GeH_4 Concentration : 0.25%
- Pressure : 0.2Torr
- RF Power Density : 88mW/cm 2
- Film Thicknesses : 7 ~ 98 nm

Raman Scattering Measurement

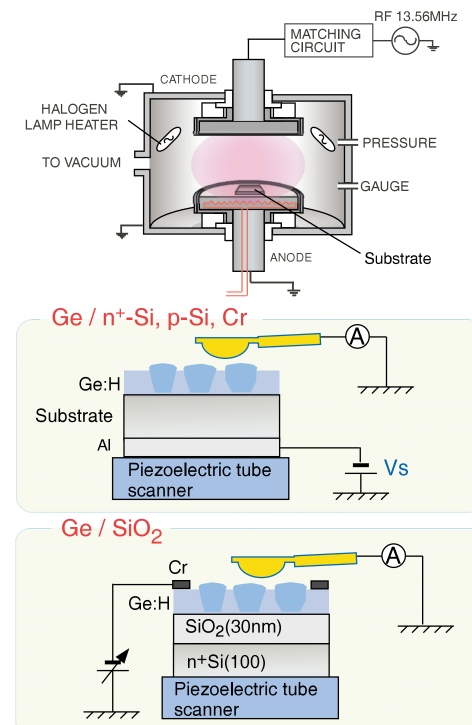
Evolution of Microcrystallites with Increasing FilmThickness

- He-Cd laser (441.6nm)
- p-polarize (glancing angle～10º)
- In Ar

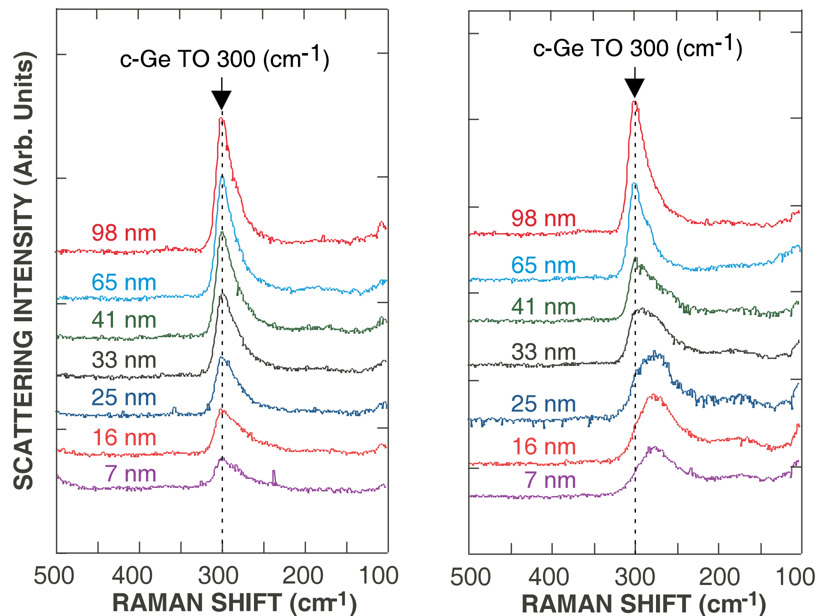
Atomic Force Microscopy

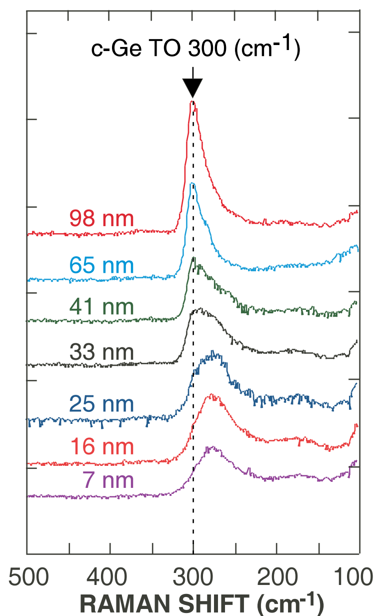
Surface Morphologies and Local Electric Transport Properties

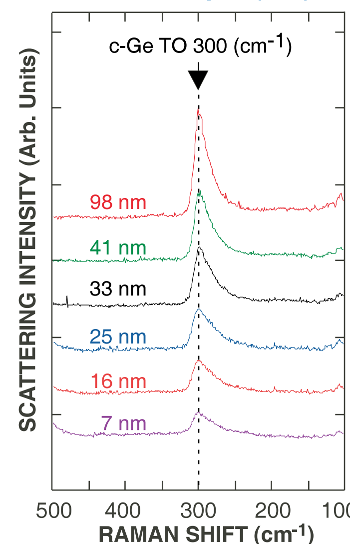
- Rh-coated Si_3N_4 cantilever
- Contact mode
- Clean room at room temperature

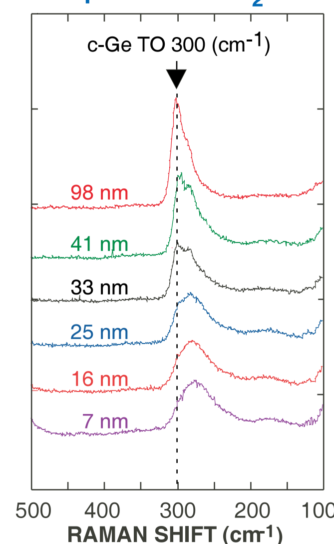


Raman Scattering Spectra



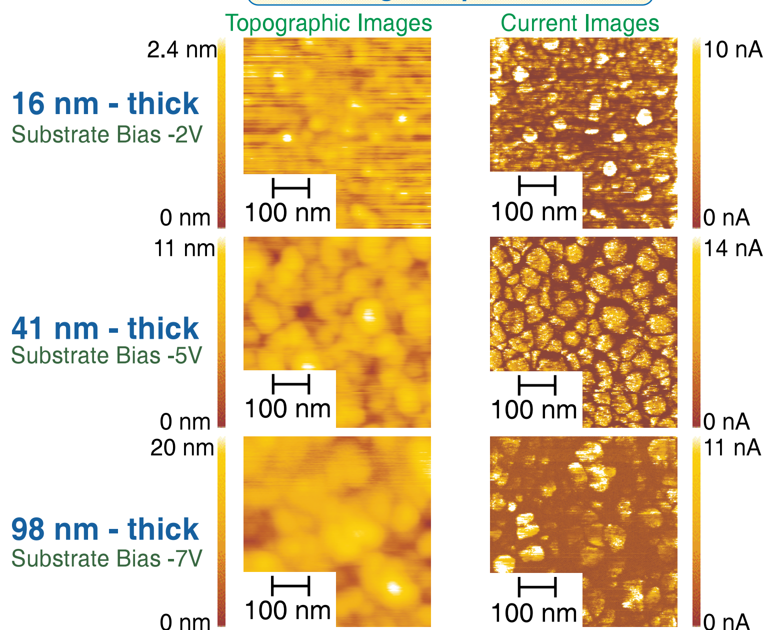






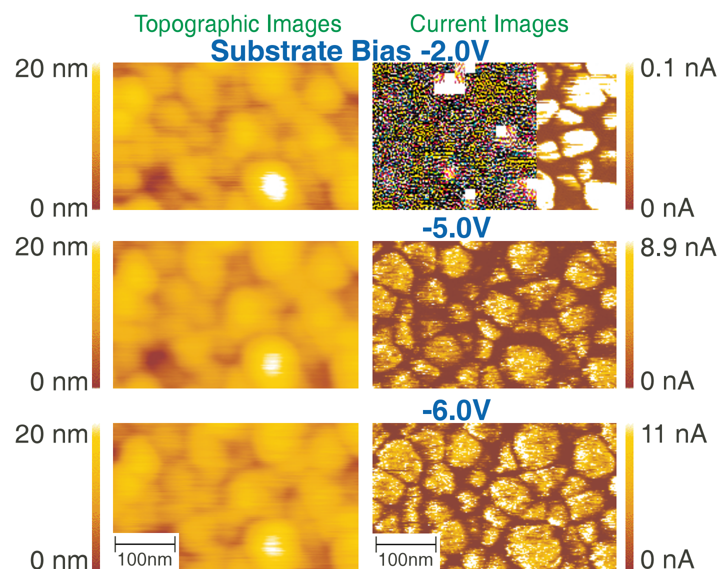
- In the film growth on n^+-Si and p-Si, the Raman signals peaked at ~300 cm^{-1} due to the Ge-Ge TO phonon mode in crystalline Ge are clearly observed even for a ~7 nm-thick film.
- In the case of the film growth on evaporated Cr and SiO_2, the formation of amorphous Ge network is dominant for films thinner than 25 nm as indicated from broad spectra around 270 cm^{-1}.

AFM Images of μc-Ge:H / n^+Si



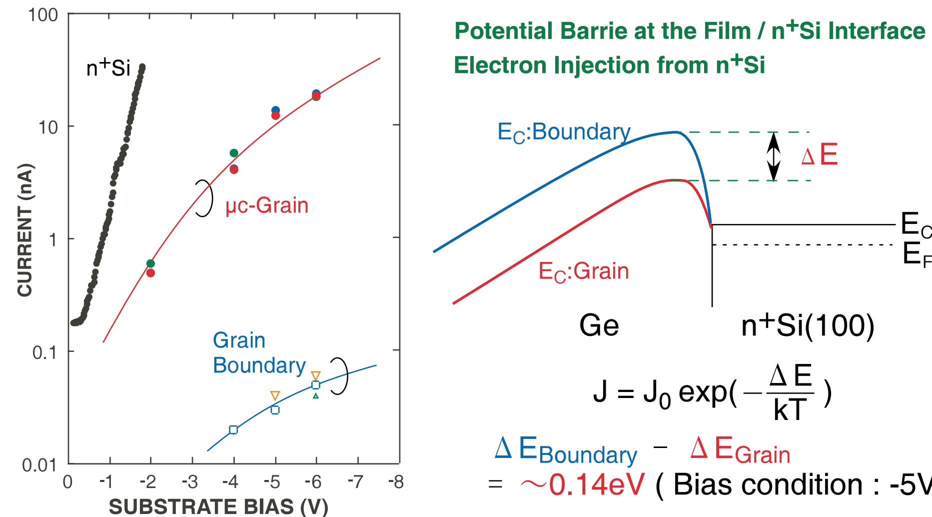
- Clear Current Images with a High Contrast among the Grains and Boundaries

AFM Images of 41nm-thick μc-Ge:H / n^+Si



- Local I-V characteristics were evaluated from an analysis of current images taken at different substrate biases.

I - V Characteristics for The Grains and Their Boundaries
41nm-thick Ge:H / n+Si(100)



Potential Barrie at the Film / n+Si Interface
Electron Injection from n+Si

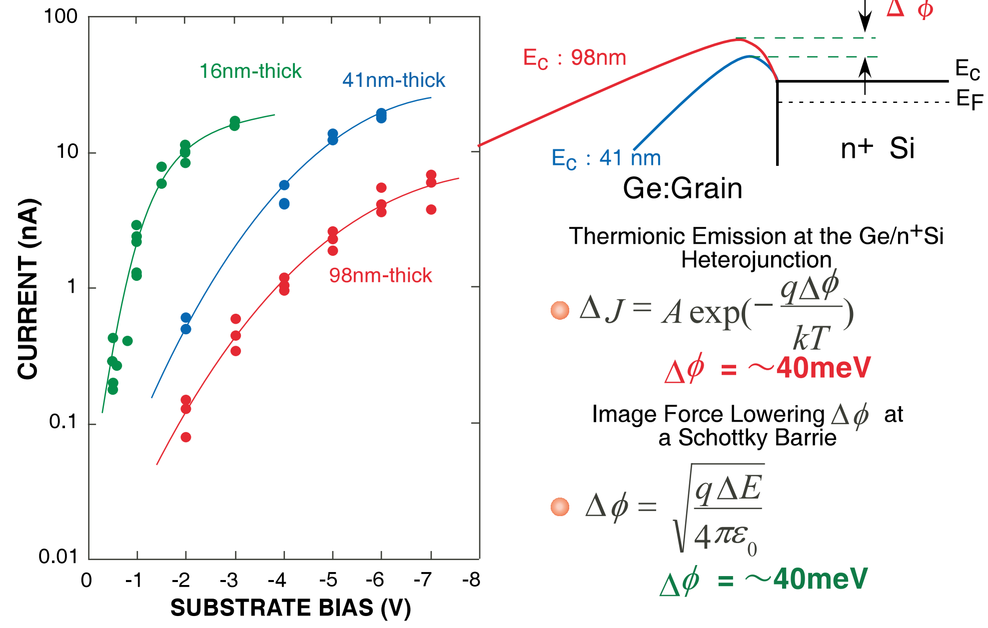
E_C:Boundary ΔE E_C E_F
E_C:Grain
Ge n+Si(100)

$$J = J_0 \exp\left(-\frac{\Delta E}{kT}\right)$$

$\Delta E_{Boundary} - \Delta E_{Grain}$
$= \sim 0.14 eV$ (Bias condition : -5V)

- The difference in the current level between grains and boundaries corresponds to the energy difference of E = ~0.14 eV for a bias condition of -5 V in the barrier height at the interface.
- The estimated value might be related to the bandgap shrinkage caused by crystallization.

I - V Characteristics for Various Thickness



E_C : 98nm Δϕ E_C E_F
E_C : 41 nm n+ Si
Ge:Grain

Thermionic Emission at the Ge/n+Si Heterojunction

- $\Delta J = A \exp(-\frac{q\Delta\phi}{kT})$

$\Delta\phi = \sim 40meV$

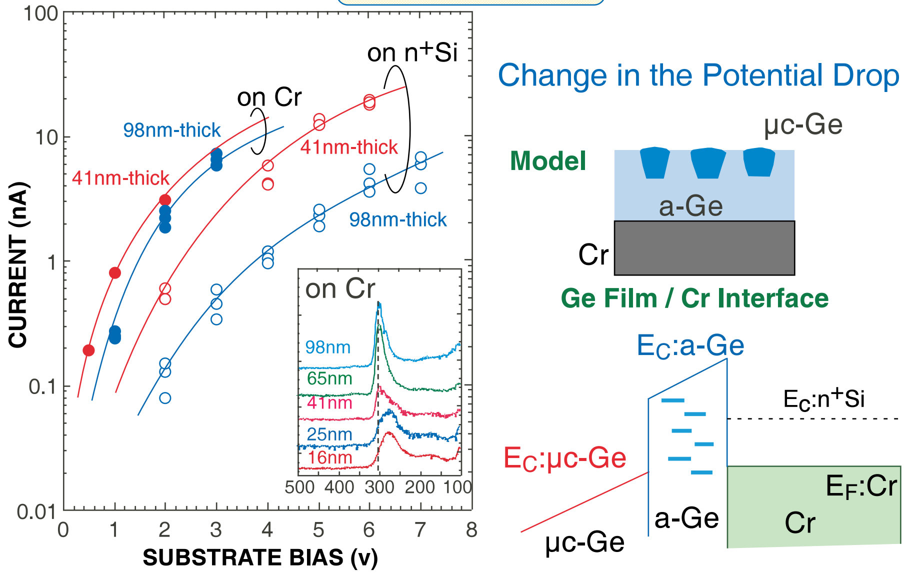
Image Force Lowering $\Delta\phi$ at a Schottky Barrie

- $\Delta\phi = \sqrt{\frac{q\Delta E}{4\pi\varepsilon_0}}$

$\Delta\phi = \sim 40meV$

- The observed thickness dependence of the current level suggests the change in the barrier height at Ge/Si(100) interface rather than the potential drop though the grains.

I-V Characteristics Ge:H / Cr



Change in the Potential Drop

Model

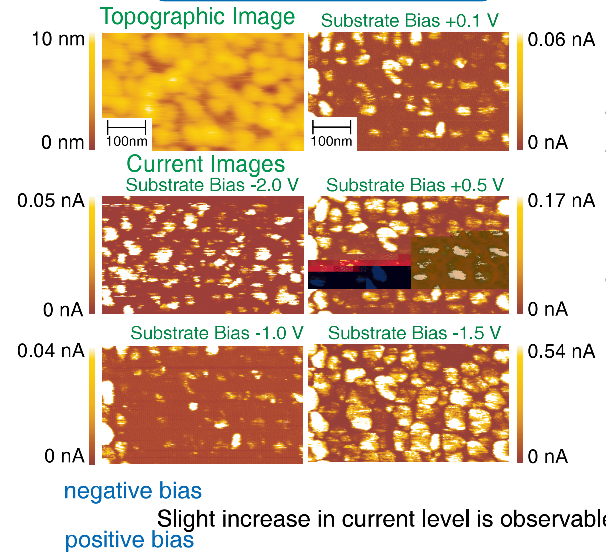
μc-Ge
a-Ge
Cr

Ge Film / Cr Interface

E_C:a-Ge
E_C:n+Si
E_C:μc-Ge
E_F:Cr
a-Ge Cr
μc-Ge

- From the viewpoint of Cr work function, the barrier height at the Ge/Cr interface is thought to be higher than the Ge/n+-Si case, which a significant reduction in the electron transport from n+-Si(100) should be observable. But it is not the case. The result of might be attributable to a defective amorphous incubation layer existing at the Ge/Cr interface.

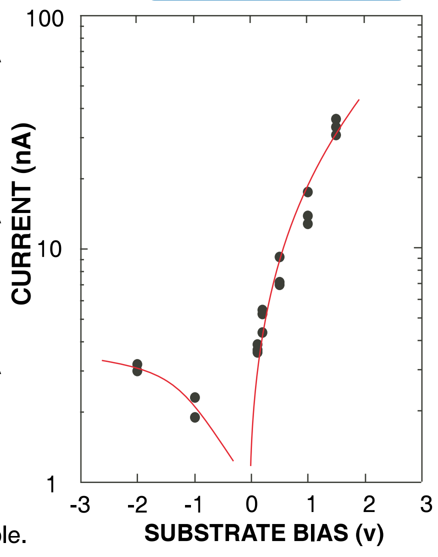
AFM Images of Different Substrate Bias
41nm-thick Ge:H / p-Si(100)



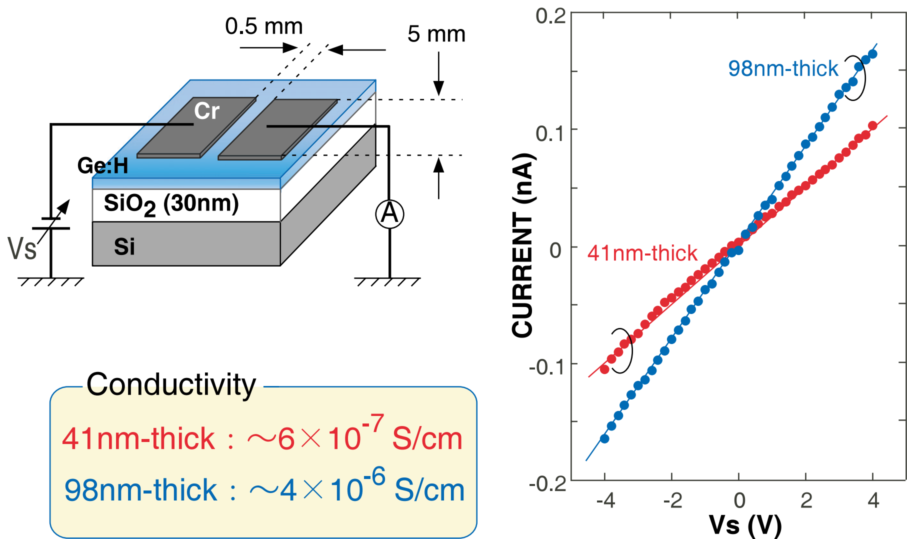
negative bias
Slight increase in current level is observable.
positive bias
Significant current increase is clearly observed.

This result suggested that a junction between p-Si and n-type-like Ge grains plays a role in the observed rectifying characteristic.

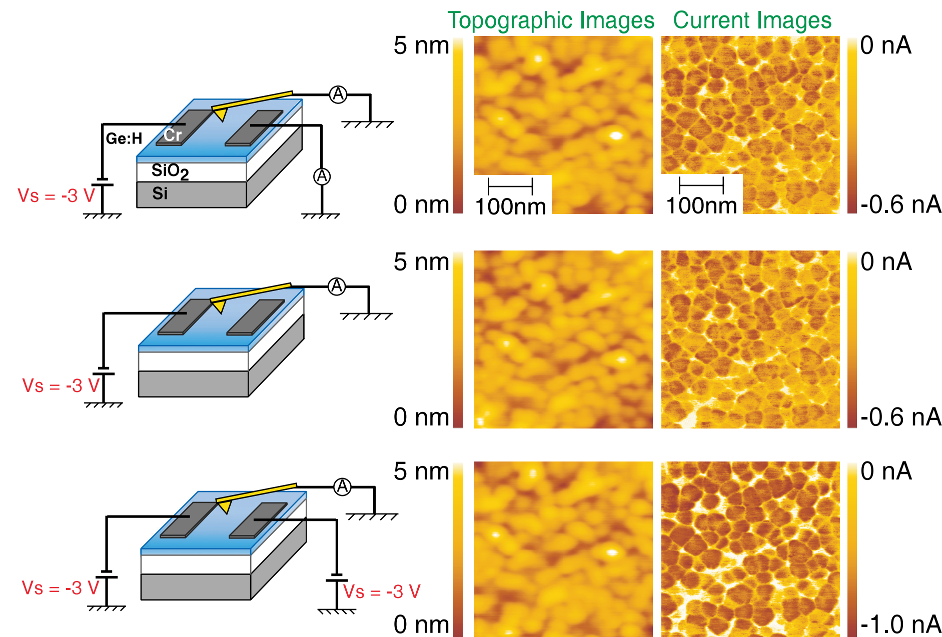
I - V Characteristics Ge:H / p-Si(100)



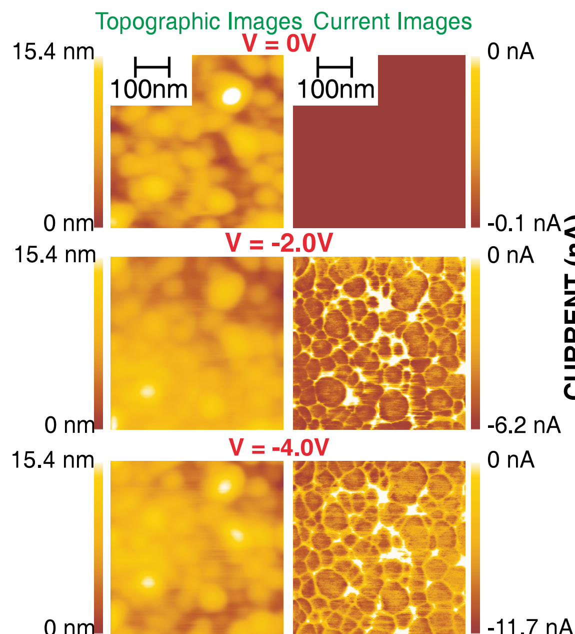
I - V Characteristics μc-Ge:H / SiO_2



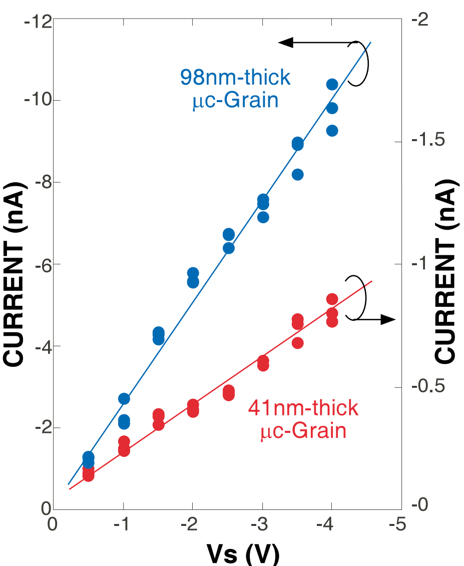
AFM Images 41nm-thick μc-Ge:H / SiO_2



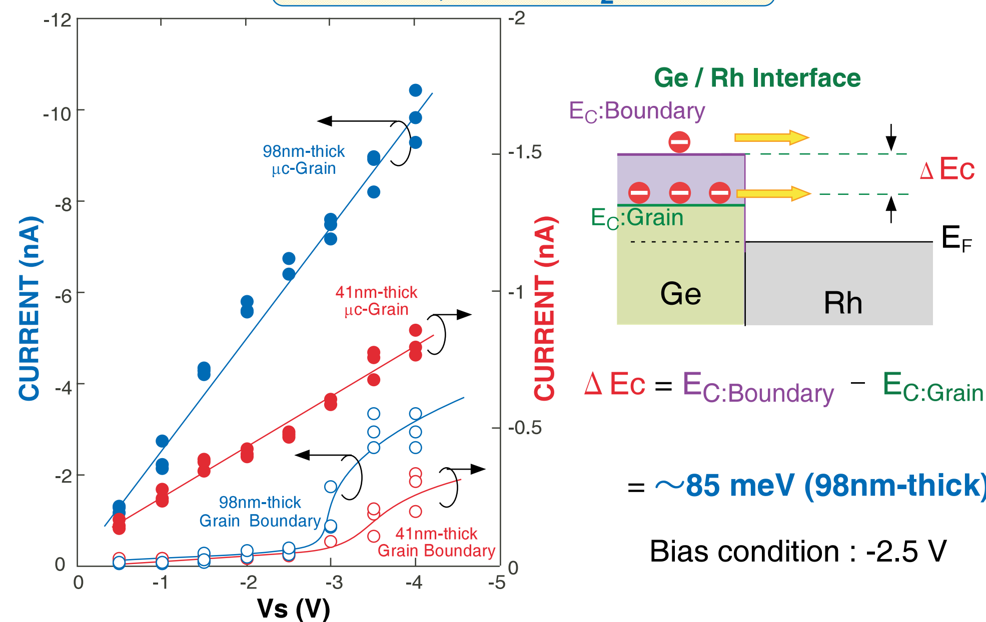
AFM Images 98nm-thick μc-Ge:H / SiO_2



I - V Characteristics μc-Ge:H / SiO_2



I - V Characteristics for The Grains and Their Boundaries μc-Ge:H / SiO_2



Summary

We have demonstrated that AFM topographic and corresponding current images in the Ge film enable us to detect the evolution of nm-scale crystalline grains on Si, Cr and SiO_2.

- Clear contrast and high spatial resolution current images for crystalline grains are obtained in good correlation with the topographic images.

- Thermionic emission through the local barrier at interface between n^+Si and Ge films consisting of Ge grains and their boundaries well explains the I-V characteristics.

- In the Ge growth on Cr, electron injection through defects in an amorphous incubation layer play a role in the relatively high conduction and the weak thickness dependence of I-V characteristics compared with Ge/n^+Si case.

- A clear rectifying characteristic of Ge grains on p-Si is also demonstrated.