Microstructure and Local Charge Distribution in Hydrogenated Nanocrystalline Silicon under Illumination Studied by Electrostatic Force Microscopy.

Rubana Priti[1] and Venkat Bommisetty[1]

[1] Electrical Engineering and computer Science, South Dakota State University, Brookings, SD 57007, USA

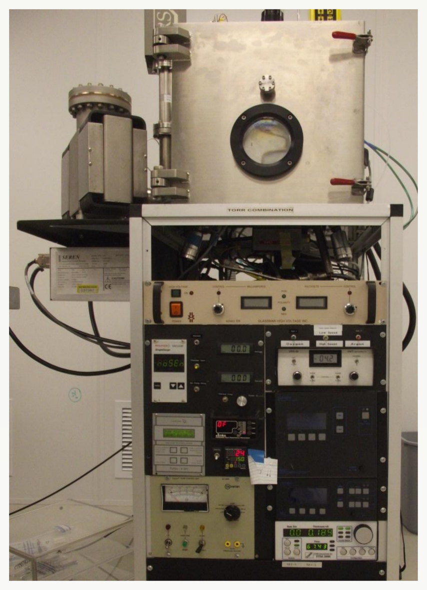
Background

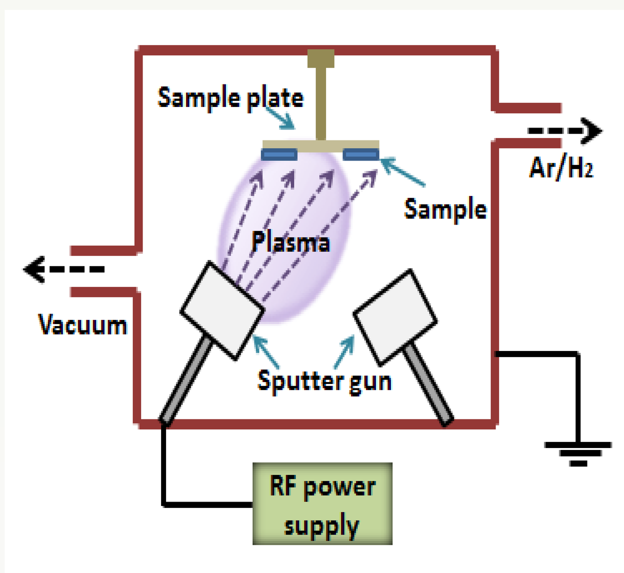
- Hydrogenated nanocrystalline silicon (nc-Si:H) is a mixed phase material of sub-nanometer scaled Si crystallites embedded in an amorphous matrix [1].
- Nc-Si:H thin films are a well-accepted material for cost-effective and flexible photovoltaics due to its easy and low-cost fabrication
- Nc-Si:H is more resilient against Light – Induced Degradation (LID) compared to its amorphous silicon counterparts [2].
- Difficulties in explaining LID in nc-Si:H
  1. complex microstructure consisting of nanometer size grains and amorphous grain boundaries [3]
  2. lack of experimental tools that can probe local electronic properties in sub-nanometer dimension

Objectives

1. Use EFM as a nanoprobe for local characterization of nc-Si:H thin films
2. Study LID and its effect on local electronic properties, such as charge distribution at grains and GBs
3. Probe qualitatively the change in charge distribution before and after LID
4. Correlate film microstructure with local charge distribution from AFM and EFM measurements

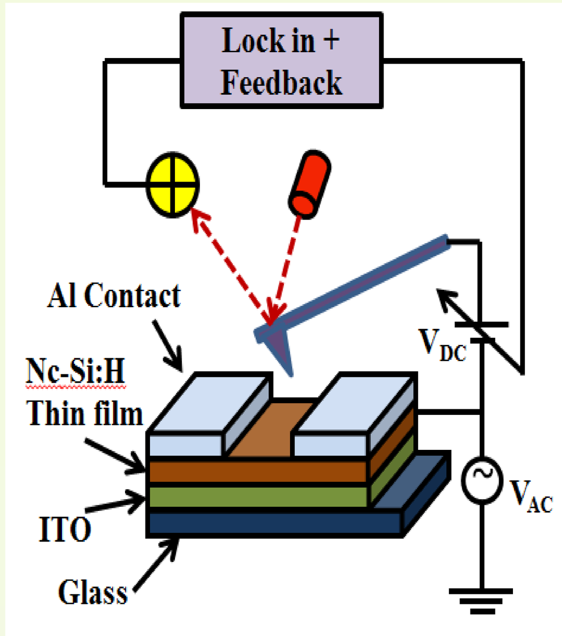
Procedure – Sputtering





- ***Thin films deposition:***
  - ✓ Rf magnetron sputtering deposition
  - ✓ Undoped crystalline silicon target
  - ✓ H_2/Ar atmosphere - H_2:Ar was 33:67
  - ✓ Temperature - 200 °C
  - ✓ Process pressure 10.4 mTorr
  - ✓ Plasma power 250 W
  - ✓ Substrate to target distance 15 cm
  - ✓ Film thickness 95 nm

Procedure – AFM and EFM



- ***Thin films characterization:***
  - ✓ Intermittent contact mode AFM using Agilent 5500 SPM Nanoscope
  - ✓ Budget sensors AFM tip
    - Pt/Ir coating, 25 nm diameter, 40 N/m force constant, 75 kHz resonance frequency
  - ✓ Tip bias from -3V to +3V
  - ✓ White LED of 100mW/cm^2 power density

Results – EFM images

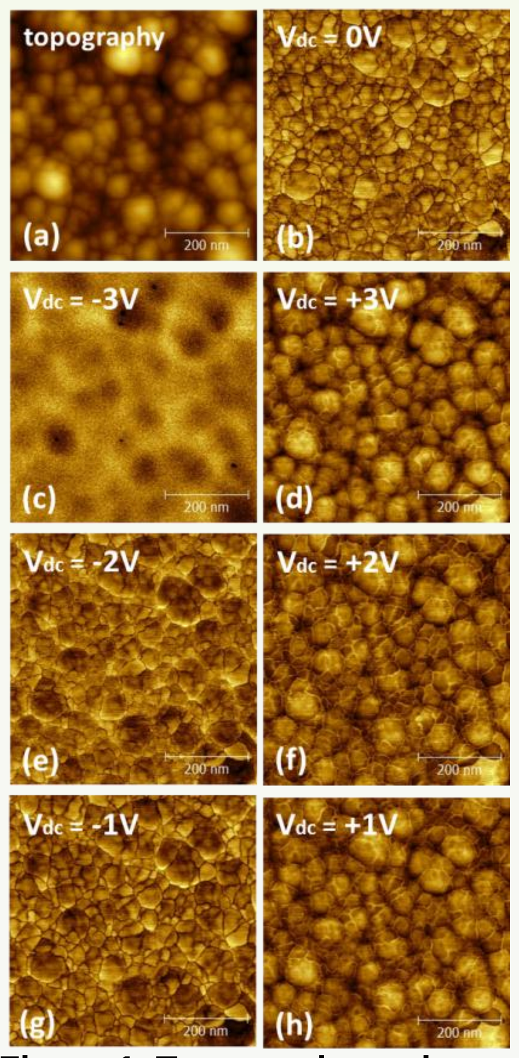


Figure 1. Topography and EFM before illumination

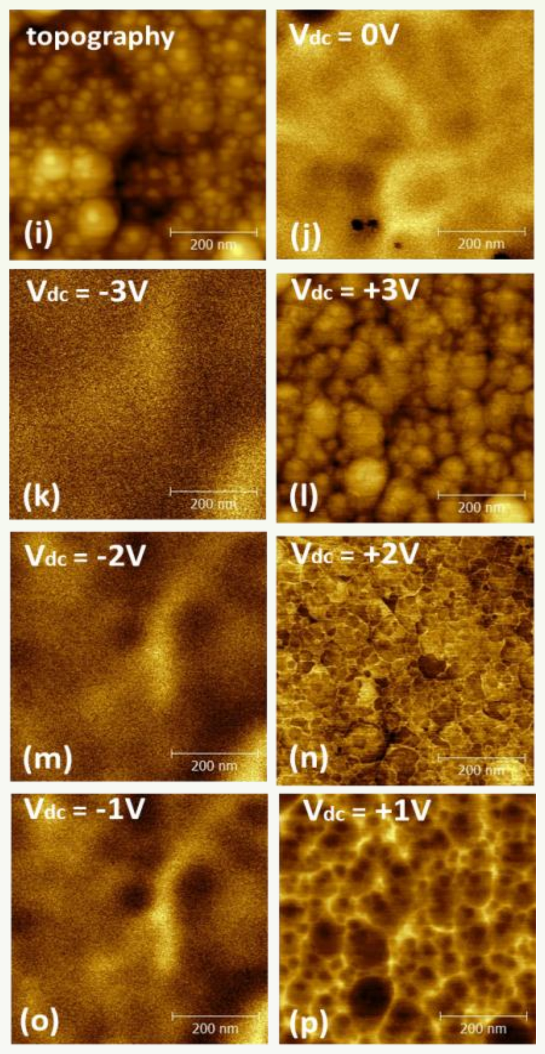
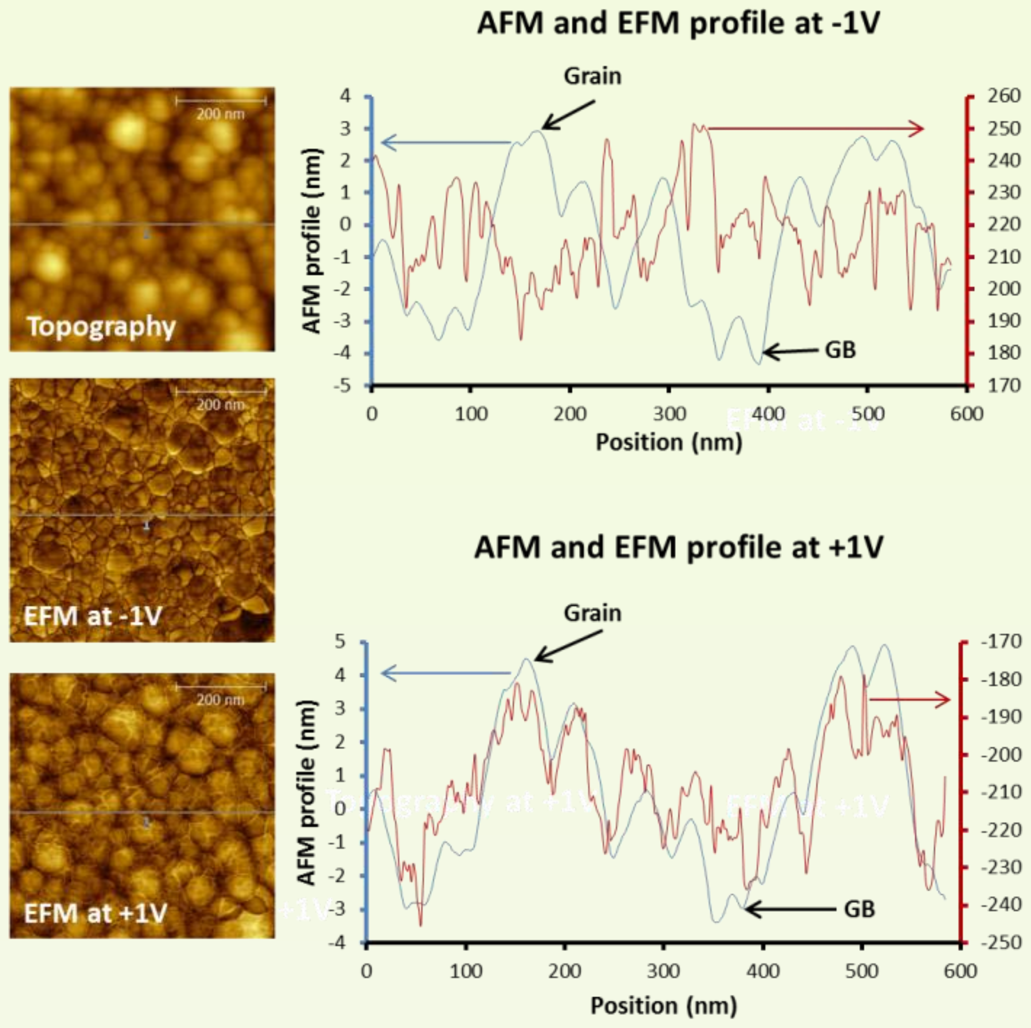


Figure 2. Topography and EFM after illumination

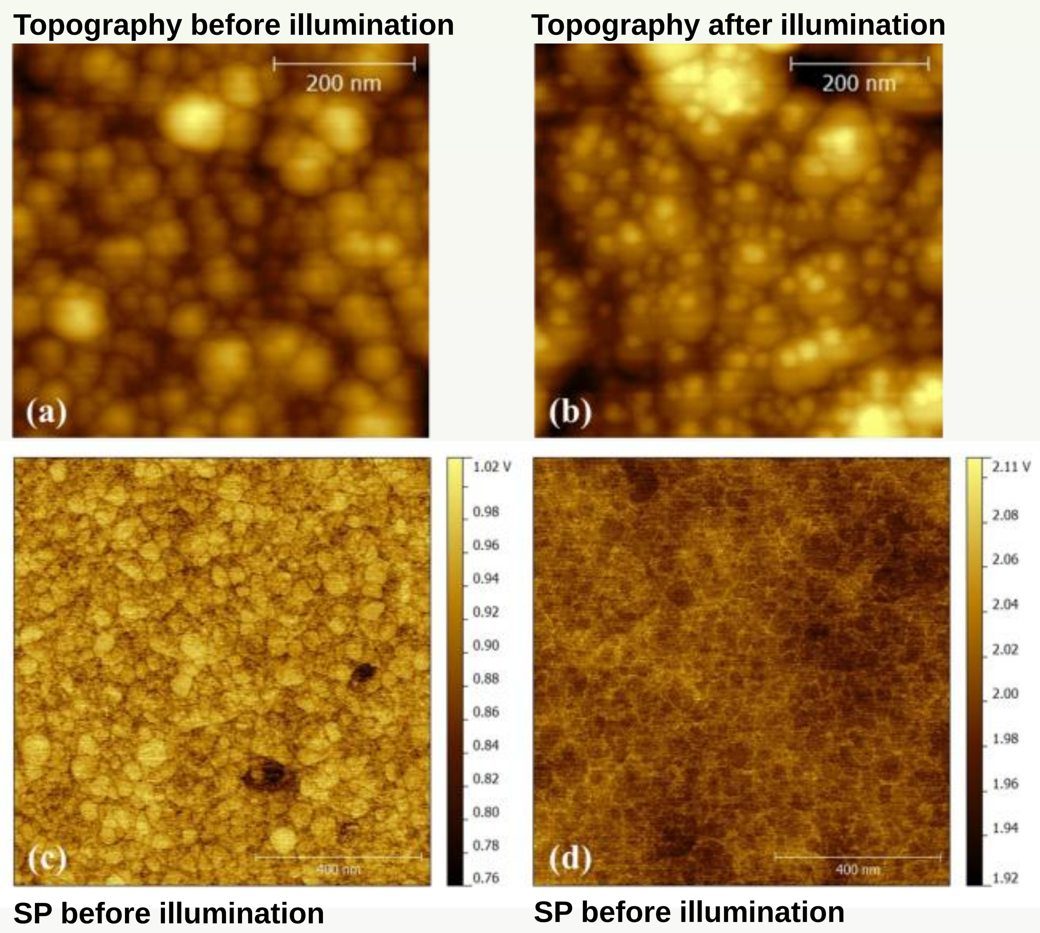
- Darker regions are at lower potential and brighter regions are at higher potential
- Change in polarity in bias voltage reverses the polarity of the surface potential indicating dominance of negative type of charge accumulation.
- Concentration of negative charges at GBs increase after LID with increasing tip-bias voltage
- Active potential barriers at large GBs is observed

Results – line profiles



- EFM offers higher spatial resolution demonstrated by potential variation at GBs between two small individual grains
- Negative correlation at negative bias; positive correlation at positive bias between 'geometric' (AFM) and 'electronic' (EFM) grains
- Modulation in the surface potential within the interior of grains, size of grains, grain clusters and GBs

Results – AFM and SP



- ***Topography:***
  - ✓ Grainy surface
  - ✓ Small individual grains and large grain clusters are separated by distinct GBs
  - ✓ Each grain cluster contains ~10 – 20 smaller grains
  - ✓ . LID evolved small blister-like structures throughout the surface

Results – AFM and SP

- ***KFM images:***
  - ✓ The density of GB increases after LID
  - ✓ Photo generated charges result in band bending at GBs
  - ✓ Newly formed blisters behave as small grains with defective and disordered GBs.

Conclusion

- Combined AFM and EFM/ KFM were used to observe the formation of active potential barrier and photo-induced charge accumulation at grains and GBs.
- Negative type of defects was found to dominate in the material whose density increased after LID
- The change in charge distribution was more pronounced near large GBs suggesting the large GBs to create metastable trap states
- EFM was demonstrated as a powerful tool for qualitative measurement of surface potential and sign of accumulated charges
- The results are in good agreement with the established theoretical models reported in the literatures.

References

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