DISTRIBUTION OF LOCAL OPEN-CIRCUIT VOLTAGE ON AMORPHOUS AND NANOCRYSTALLINE MIXED-PHASE Si:H AND SiGe:H SOLAR CELLS

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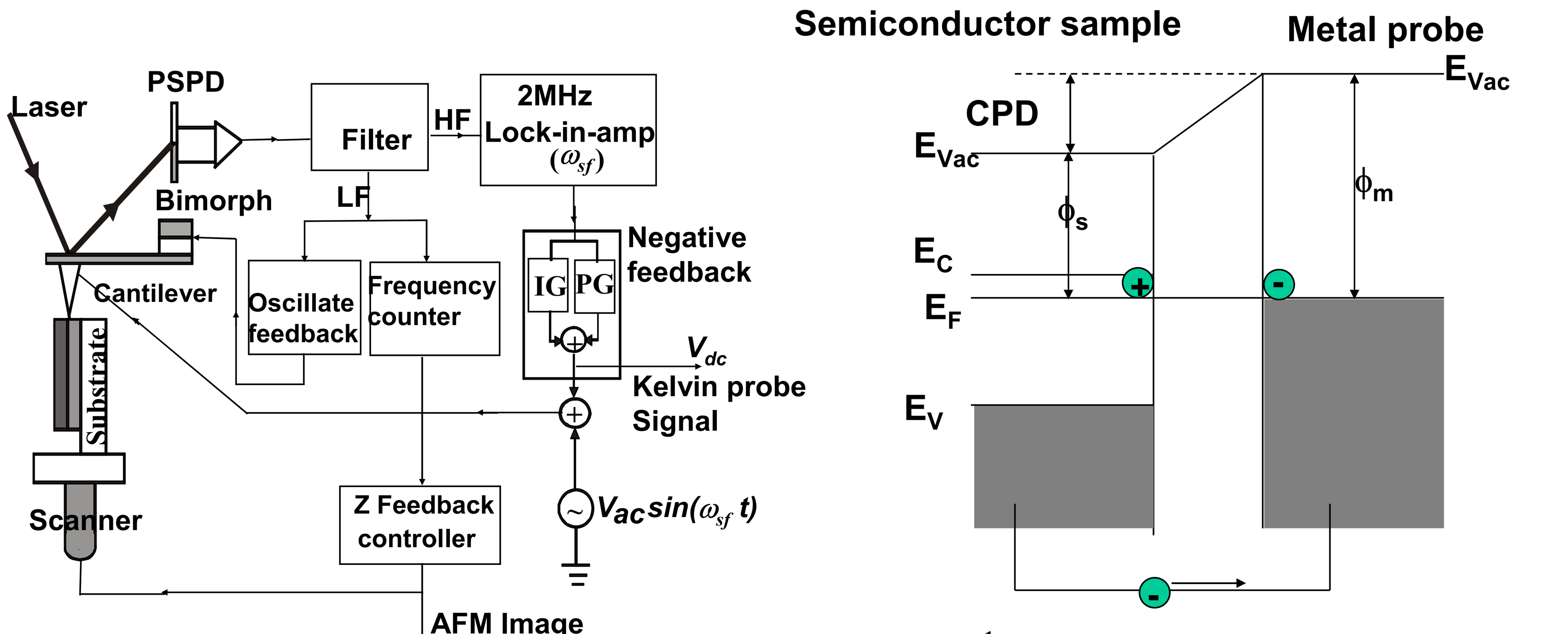
BACKGROUND

- The best a-Si:H solar cells are deposited under the condition close to the amorphous/nanocrystalline transition but still in the amorphous regime.
- The best nanocrystalline silicon (nc-Si:H) solar cells are deposited under the condition close to the transition but in the nanocrystalline regime
- The devices made on the transition condition show characteristics of a-Si:H/nc-Si:H mixed-phase, having an V_{oc} between 1.0 and 0.5 V.
- The mixed-phase solar cells show light-soaking-induced V_{oc} increase, which is opposite to the light-soaking-induced V_{oc} decrease in conventional a-Si:H cells.
- An original explanation for the light-induced V_{oc} increase was light-induced structural changes from the crystalline to amorphous phase.
- A complementary model is two parallel-connected diodes, one with a-Si:H diode characteristics and the other with nc-Si:H diode characteristics.
- We have recently found an aggregation of nc-Si:H phase in the a-Si:H phase matrix, by imaging the local current flow using conductive AFM.
- ***In this presentation, we report on local V_{oc} distribution on the mixed-phase solar cells, by using Scanning Kelvin Probe Microscopy (SKPM).***

EXPERIMENTAL

Scanning Kelvin Probe Microscopy (SKPM)



$$E = \frac{1}{2}C(Vt-Vs)^2$$

$$F = \frac{\partial E}{\partial z} = \frac{1}{2}\frac{\partial C}{\partial z}(Vt-Vs)^2$$

$$E = \frac{1}{2}C(Vt + V_{ac}Sin(\omega t) - Vs)^2$$

$$F = F_0 + F_1 + F_2$$

$$F_0 = \frac{1}{2}\frac{\partial C}{\partial z}\left[(Vt-Vs)^2 + \frac{1}{2}V_{ac}^2\right]$$

$$F_1 = \frac{\partial C}{\partial z}(Vt-Vs)V_{ac}Sin(\omega t)$$

$$F2 = -\frac{\partial C}{\partial z}V_{ac}^2 COS(2\omega t)$$

If $Vt = Vs$, $F_1 = 0$,

$Vt = Wt + Vb$

$Vs = Ws$

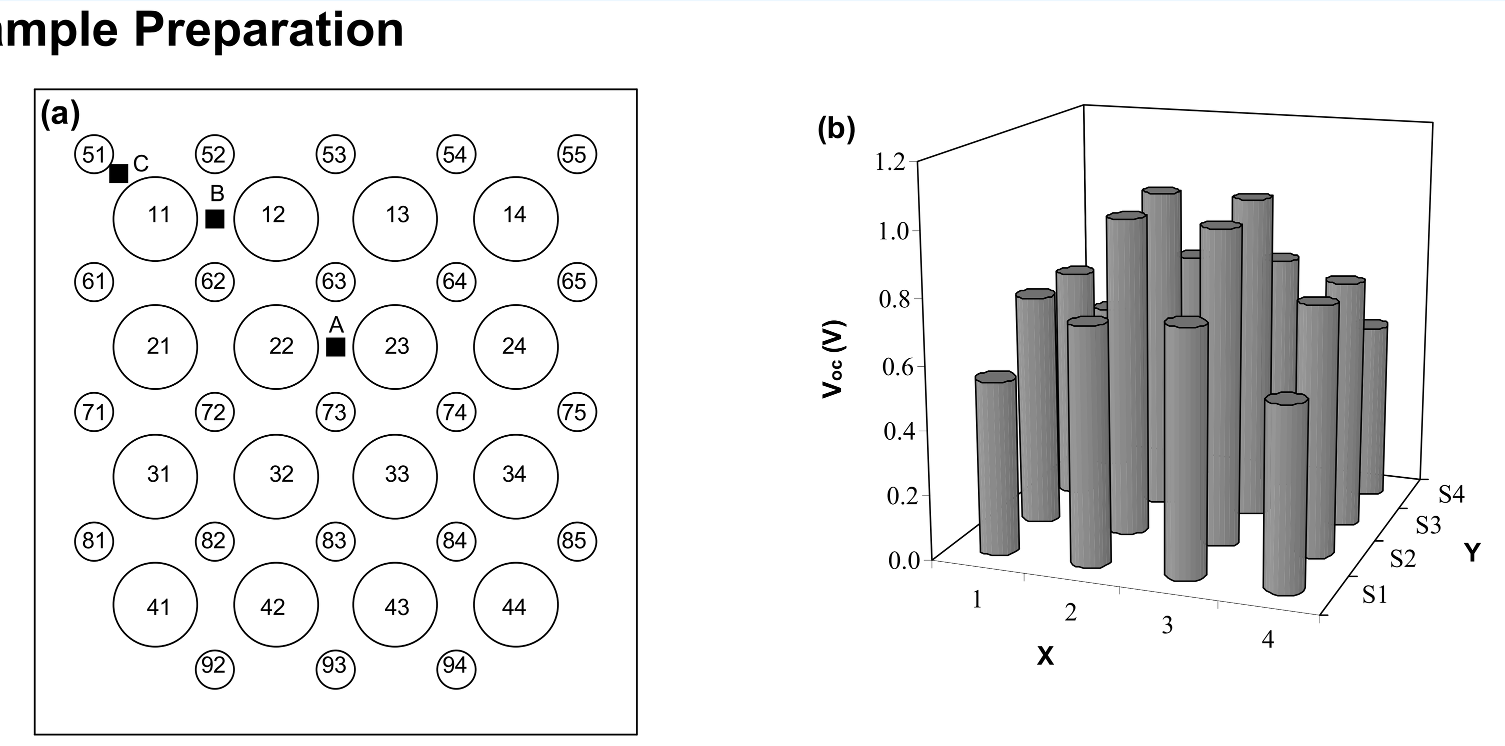
$Vb = Ws - Wt$

Wt --- Constant

Vb* maps *Ws

- •SKPM is based on the non-contact mode of atomic force microscopy (NC-AFM)
- •SKPM measures contact potential difference (CPD) between the tip and sample surface
- •SKPM detects the Coulomb force between the tip and sample using second resonant frequency of the cantilever
- •Spatial resolution of SKPM: ~30 nm; Energy resolution: ~10 meV

Sample Preparation

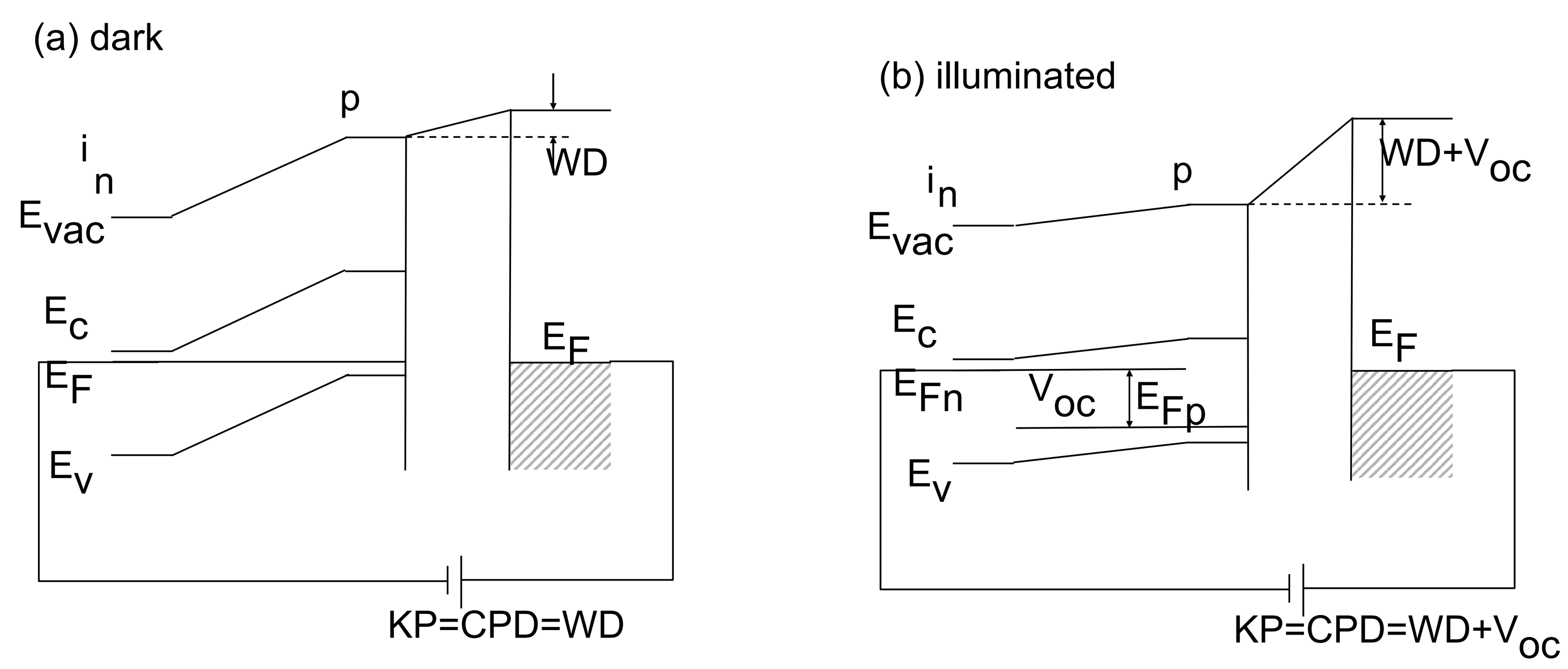


- •*i*-layer was deposited in a-Si:H/nc-Si:H transition condition.
- •Characteristics of *i*-layer are sensitive to location on the substrate, center: a-Si:H, corner: nc-Si:H; edge: mixed-phase.

SUMMARY

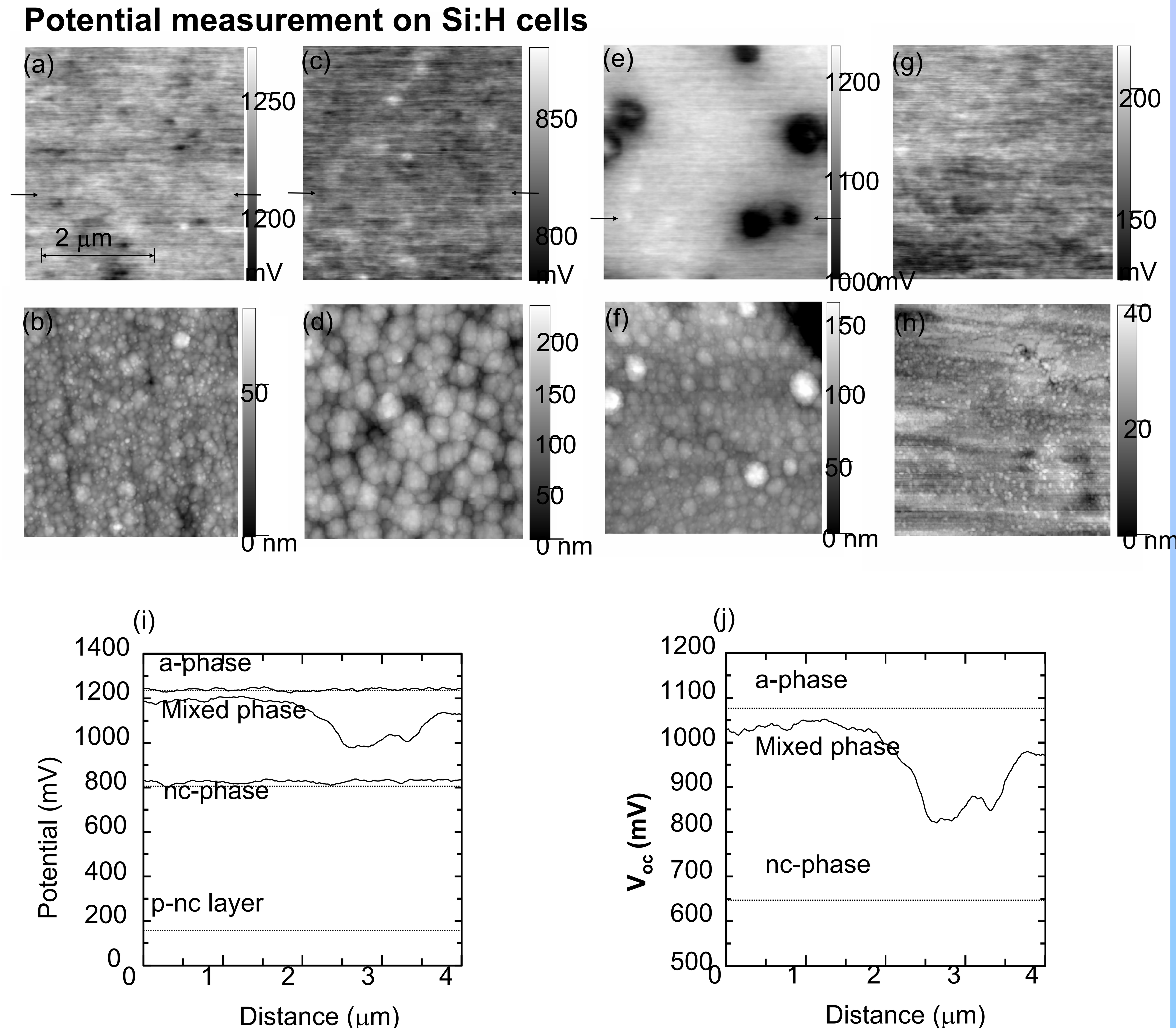
By combining SKPM and AFM, we have developed a method to measure the local V_{oc} distribution in mixed-phase solar cells. The results clearly show the nanocrystalline aggregation. The V_{oc} is smaller in the nanocrystalline aggregates than in the surrounding amorphous matrix, and the transition from the low to high V_{oc} is a gradual change. Although there are some lateral charge redistributions, a clear distinction between the amorphous and nanocrystalline regions has been observed. The current SKPM results and previous C-AFM results provide extra support for the two-diode model for explaining the carrier transport in the mixed-phase solar cells

RESULTS



•KP measures the workfunction difference (WD) when it is in the thermoequilibrium state in the dark.
•KP measures the sum of WD and local V_{oc} when it is illuminated.

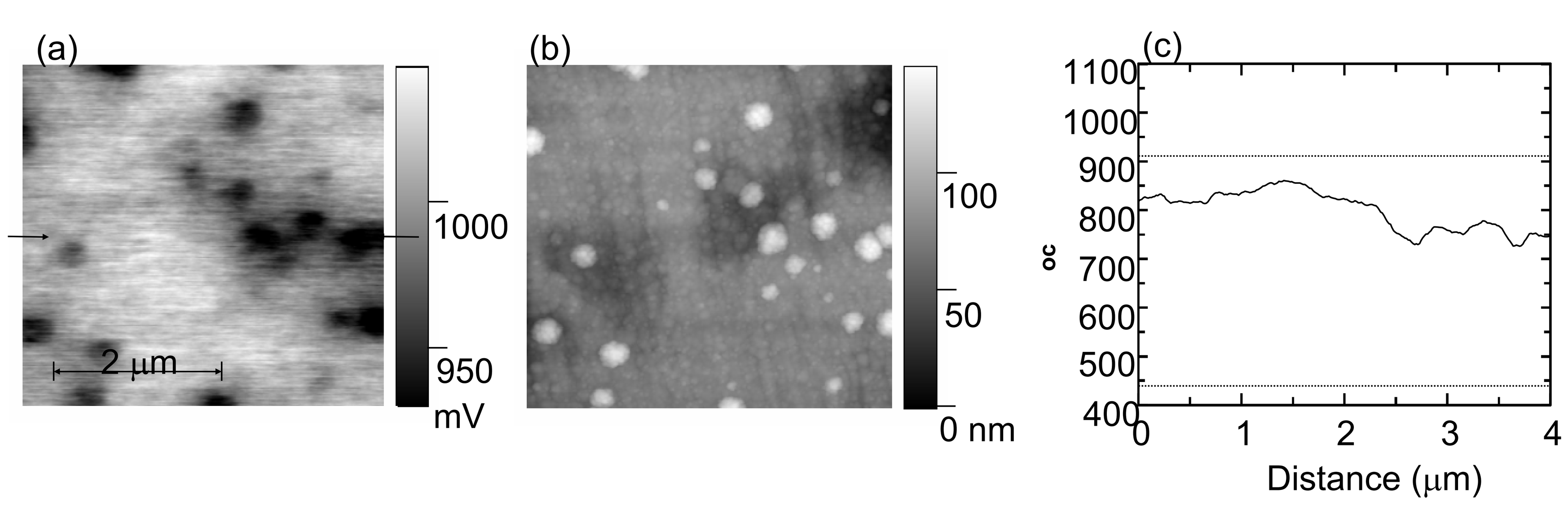
Potential measurement on Si:H cells



(a) and (b): SKPM potential and AFM topographic images on a-Si:H region.
(c) and (d): on nc-Si:H region.
(e) and (f): on mixed-phase region.
(g) and (h): on p-layer directly deposited on stainless steel substrate.
(i): Example potential line profiles in the SKPM images.
(j): Line profile of Voc deduced from the potential profiles.

- **•Nanocrystallites aggregate in the amorphous matrix with an aggregation size of ~0.5 μm.**
- **•The V_{oc} distribution shows valleys in the nanocrystalline aggregation area.**
- **•The transition from low to high V_{oc} regions is a gradual change within a distance of around 1 μm.**
- **•The minimum V_{oc} value in the nanocrystalline clusters in the mixed-phase region is larger than the V_{oc} of a nc-Si:H single phase solar cell.**

Potential measurement on SiGe:H alloy cells



(a): SKPM potential image; (b) AFM; (c): V_{oc} Line profile.

- **•nc-SiGe:H aggregation is smaller than the case of Si:H**
- **•V_{oc} on the aggregation is more smooth-out than the case of Si:H**

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