PROFILING THE BUILT-IN ELECTRICAL POTENTIAL IN III-V MULTIJUNCTION SOLAR CELLS

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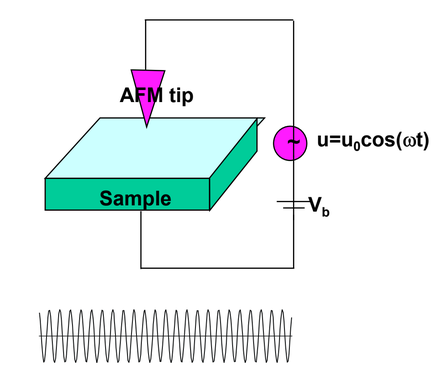
BACKGROUND

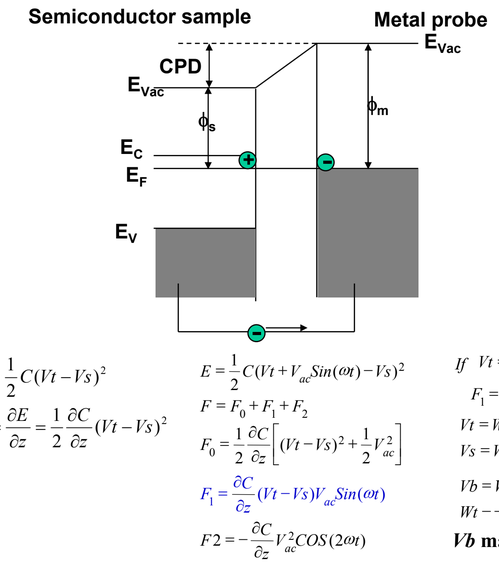
- Built-in potential is a key factor in photovoltaic devices. However, it's characterization has been limited to indirect ways such as I-V and C-V measurements.
- We have recently established and applied scanning Kelvin probe microscopy (SKPM), a AFM-based nanometer-scale electrical characterization technique, to the photovoltaic devices.
- SKPM provides us a technique to assess the quality of p-n junctions.
- We have measured the built-in potential on cross-sectional surface of solar cells:
- – III-V: $GaInP_2$ single-junction
- $GaInP_2$/GaAs two-junctions
- – Thin film: CIGS
- a-Si
- We have reported the potential measurement by using a air-SKPM. Air molecules are adsorbed on the cross-sectional surface and affect the potential measurement.
- The air-SKPM uses a laser beam of 1.85 eV for the AFM operation. The photon energy is lager than band gaps of most photovoltaic material and the laser is absorbed by the solar cells.

- ***In this presentation, we report on a potential measurement by using a UHV-SKPM. Air molecule adsorption is avoided. The UHV-SKPM uses a laser of 1.4 eV. Light absorption in the $GaInP_2$/GaAs cells is minor.***

MEASUREMENT TECHNIQUE

Principle of 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 $Vt = Vs$

$F_1 = 0,$

$Vt = Wt + Vb$

$Vs = Ws$

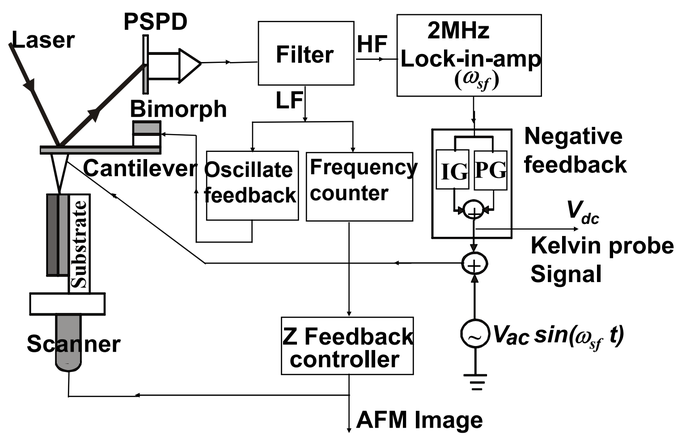
$Vb = Ws - Wt$

Wt − − − Constant

Vb* maps *Ws

•SKPM measures contact potential difference (CPD) between the tip and sample surface
•SKPM detects the Coulomb force between the tip and sample, and use it as feedback source in determining the Kelvin probe signal.
•Spatial resolution: ~30 nm; Energy resolution: ~10 meV

SKPM setup



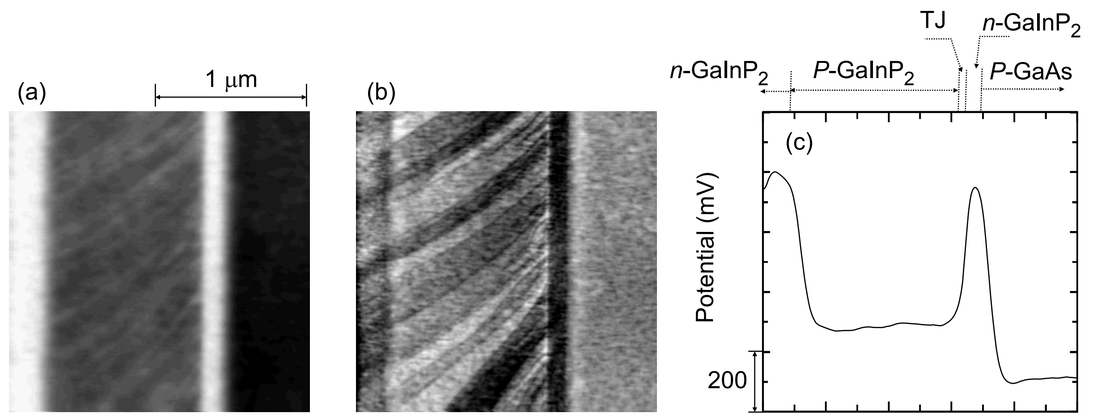
• SKPM is based on the non-contact mode of atomic force microscopy (NC-AFM)
• The oscillation signal of the cantilever is separated to low and high frequencies at the first and second resonant frequencies
•The low frequency signal is used for detecting the topography of the sample surface
•The high frequency signal is used for measuring the Kelvin probe signal.

SUMMARY

We have observed three electrical potentials at the top, tunneling, and bottom junctions of $GnInP_2$/GaAs tandem-junction solar cells, by performing the UHV-SKPM measurement. The effect of laser illumination was avoided by using GaAs laser with photon energy of 1.4 eV for the AFM operation. We also observed higher potentials at the atomic steps than on the terraces for both p-type $GaInP_2$ epitaxial layer and p-type GaAs substrate, and found that the potential at steps of GaAs substrate depends on the step directions.

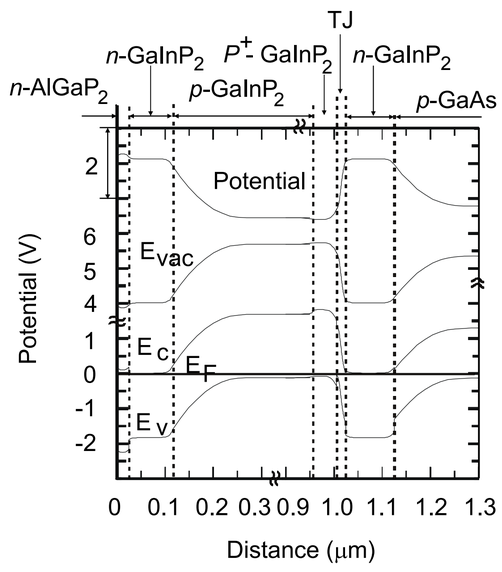
RESULTS

Potential measurement on $GaInP_2$/GaAs tandem cells



•(a): SKPM potential image; (b): AFM topographic image; (c): Potential profile obtained by averaging (a) along the vertical direction.
•Three potentials at the top, the tunneling, and the bottom junctions.
• Measured potential values are smaller than the calculated potentials in the bulk, presumably due to surface Fermi level pinning.
• The surface Fermi level may be pinned at defect states, and the defects were created upon cleaving.
•Higher potential at the steps of *p*-$GaInP_2$ layer than on the terraces.

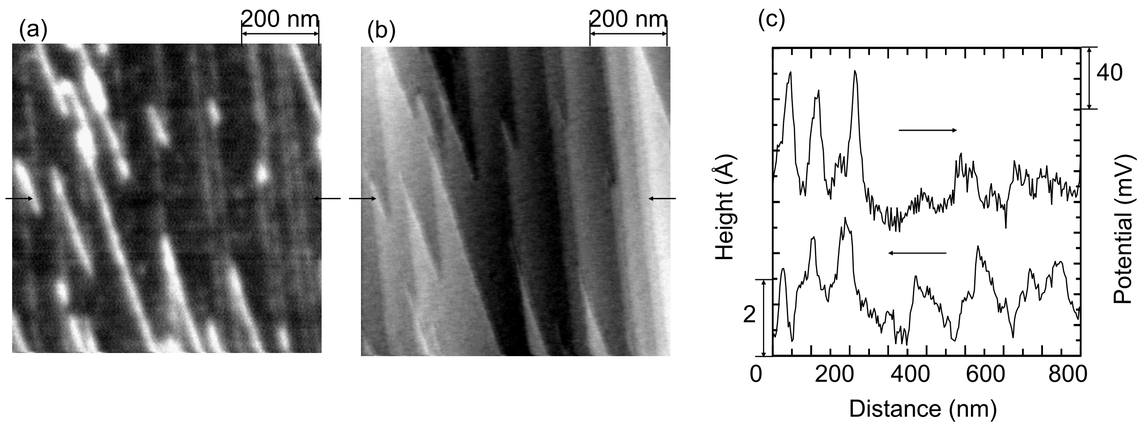
Calculated Potential in the thermoequilibrium state in the bulk



Parameters used in the calculation

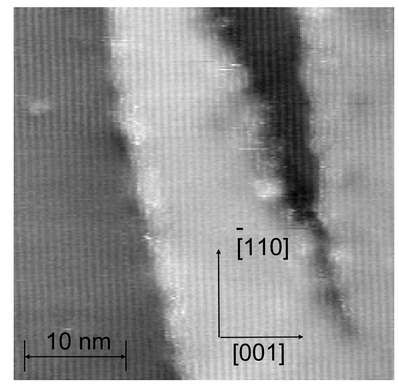
	Name	Material	Type	Thickness (nm)	Doping ($\times 10^{17}$)	Eg (eV)	Electron Affinity (eV)
Top cell	Window	$AlInP_2$	n	25	10	2.35[9]	3.78[10]
	Emitter	$GaInP_2$	n	90	10	1.85[11,12]	4.01[13]
	Base	$GaInP_2$	p	840	1	1.81	4.01[13]
	BSF	$GaInP_2$	p	50	10	1.89[11,12]	3.93[13-15]
Tunneling Junction	p-layer	GaAs	p	10	100	1.42[16]	4.07[16]
	n-layer	GaAs	n	10	100	1.42[16]	4.07[16]
Bottom cell	Emitter	$GaInP_2$	n	100	10	1.85[11,12]	4.01[13]
	Base	GaAs	p	350	1	1.42[16]	4.07[16]

Potential measurement on the GaAs substrate



•(a): SKPM potential image; (b): AFM topographic image; (c): line profiles in (a) and (b)
•Steps are single atomic steps.
•Potential at the steps are higher than on the terraces.
•Height of the potential depends on the angle of step; the steps with a larger angle have a larger potential than the steps with a smaller angle do, presumably due to the unbalanced cation and anion at the steps.
• The angles with the [$\bar{1}$10] direction is observed from the STM image take on the same sample area.

Occupied-state STM image; V_s=-2.0V, I_t=0.1 nA



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