A national laboratory of the U.S. Depart[...] Energy
Office of Energy Efficiency & Ren[...] Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

INVESTIGATION OF JUNCTION PROPERTIES OF CdS/CdTe SOLAR CELLS AND THEIR CORRELATION TO DEVICE PROPERTIES

R.G. Dhere, Y. Zhang, M.J. Romero, S.E. Asher, M. Young, B. To, R. Noufi and T.A. Gessert.

Acknowledgements- K. Ramanathan, T. Coutts.
DOE contract # DE-AC36-99GO10337

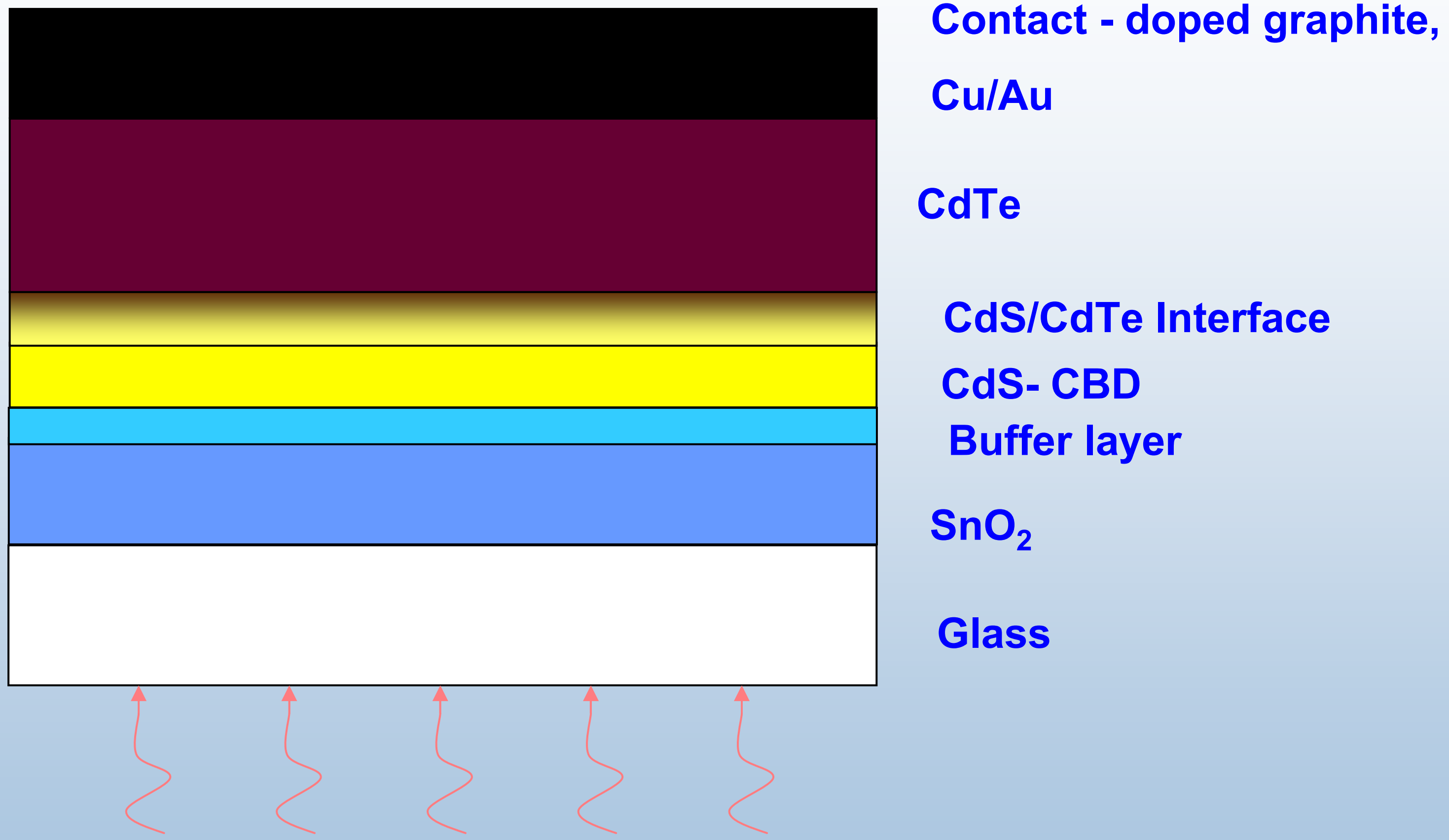
NREL/PR-520-43286
Presented at the 33rd IEEE Photovoltaic Specialist Conference held May 11-16, 2008 in San Diego, California

NREL is operated by Midwest Research Institute • Battelle

Objective - Junction Studies

- Understand the nature of the junction in the CdTe/CdS device
- Correlate the device fabrication parameters to the junction formation
- Develop a self consistent device model to explain the device properties

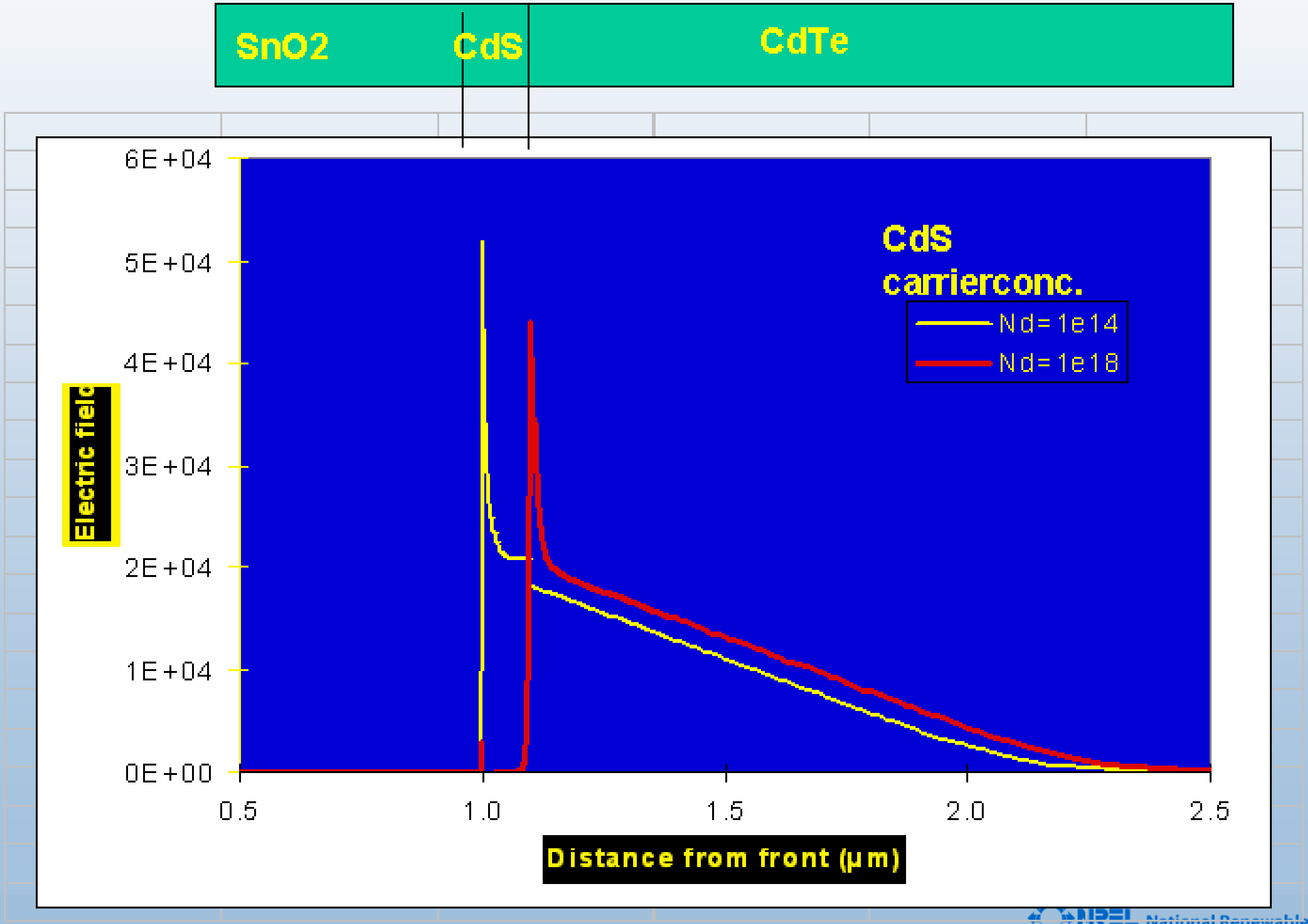
Detailed analysis of CdS/CdTe and SnO_2/CdTe devices prepared using CSS CdTe.



CdTe Device Structure

n^+-p device model for CdS/CdTe device (6/95)- based on blue QE loss:

- One sided junction with depletion width entirely in CdTe.
- Only field assisted collection.



Problems with the n^+-p model

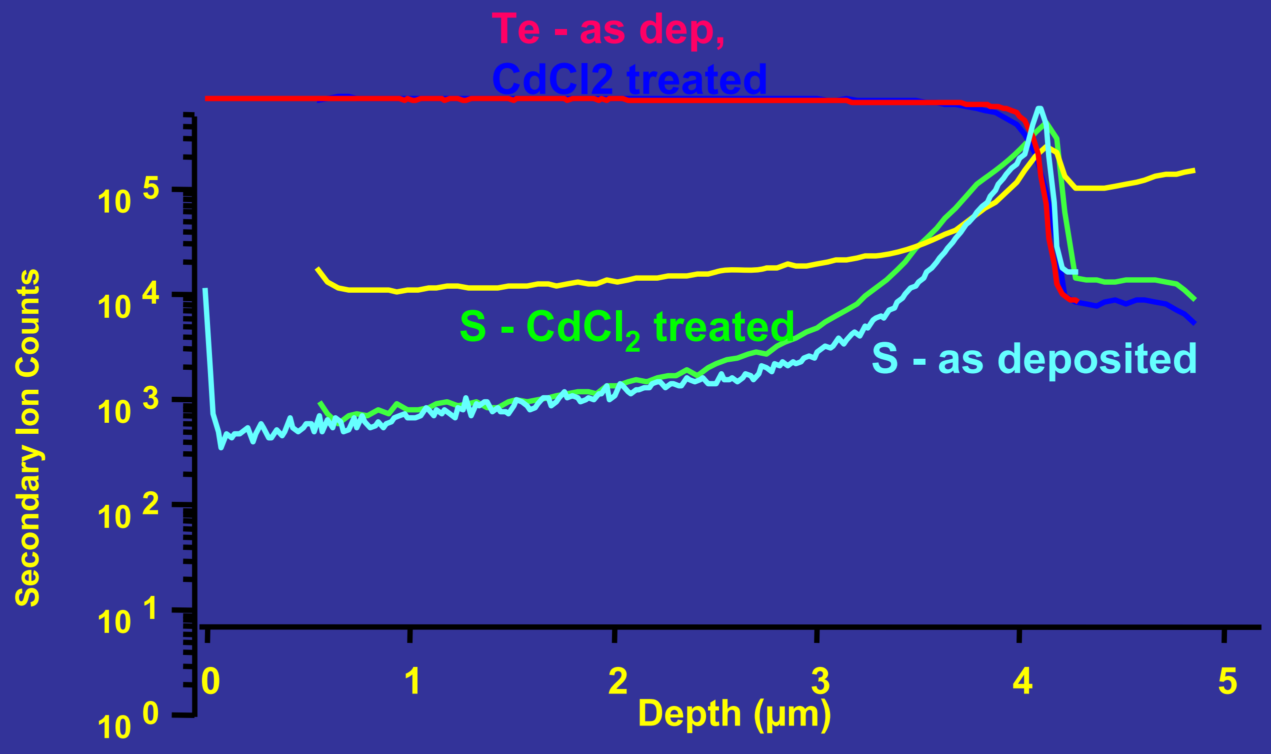
•Phenomenological Model – can explain the device performance but without physical basis.

•CBD CdS has carrier concentration around $10^{13}/cm^3$ which is even less than CdTe

Here we present our interface/junction analysis using Secondary Ion Mass Spectrometry (SIMS), Modulated reflectance techniques and Electron Beam Induced Current (EBIC) to elucidate the junction properties.

SIMS Results

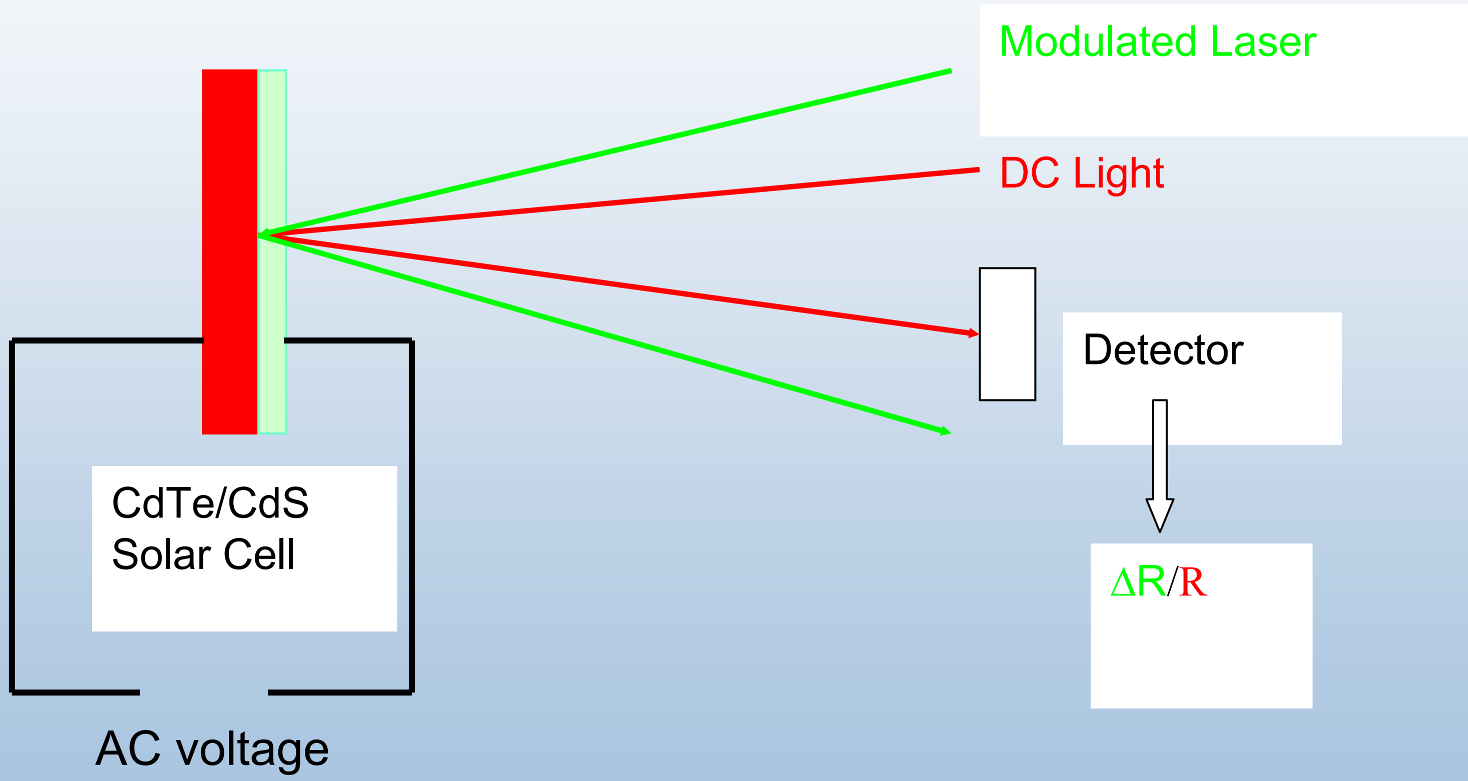
- Roughness of the samples (RMS – 0.5 μm) makes it impossible to resolve the features at CdS/CdTe interface.
- NREL SIMS and Microscopy groups developed sample preparation with polishing to improve the interface resolution.


Te - as dep,
CdCl2 treated
S - CdCl2 treated
S - as deposited
Secondary Ion Counts
10 0
10 1
10 2
10 3
10 4
10 5
0
1
2
3
4
5
Depth (µm)

Observations

- Interdiffusion at CdS/CdTe interface increases with T_{sub} and $CdCl_2$ HT
- Accumulation of Cl at CdS/CdTe interface after $CdCl_2$ HT. Level of Cl increases with level of HT
- Cl is a n-type dopant in both CdS and CdTe; also in the intermixed alloy

Photo- or Electro-Modulated Reflectance (PR or ER)



Reflectance modulation

$$R = \left| \frac{n - n_a}{n + n_a} \right|$$

$n^2 = \varepsilon_1 + i\,\varepsilon_2$, $\quad n_a^2 = \varepsilon_a$ (real)

Near band-gap $\Rightarrow$ major contribution is from $\Delta\varepsilon_1$:

$$\frac{\Delta R}{R} \approx \alpha \Delta \varepsilon_1$$

Fitting Modulation Reflectance Spectrum

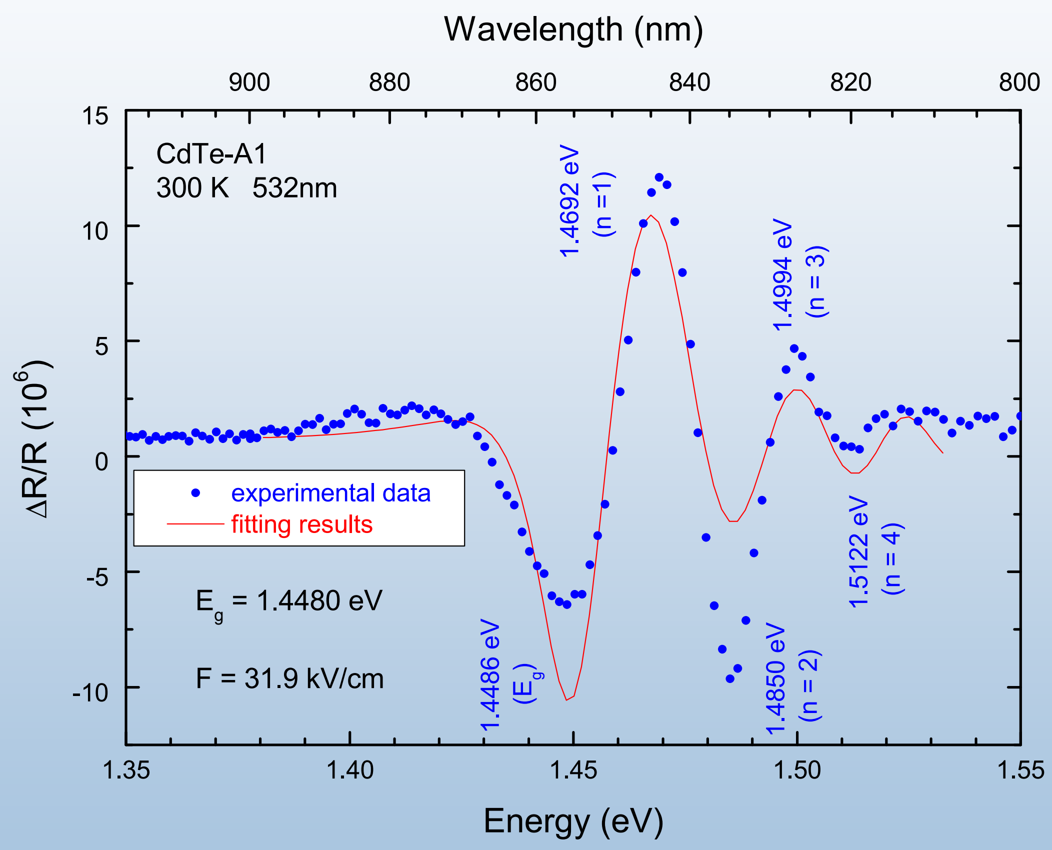
$$\Delta\varepsilon_1 = \frac{2e^2\hbar^2 |\vec{e}\cdot\vec{P}_{cv}|^2}{m^2(\hbar\omega)^2}\left(\frac{2\mu_0}{\hbar^2}\right)^{3/2}\sqrt{\hbar\Omega_0}\left(G\left(\frac{E_g-\hbar\omega}{\hbar\Omega_0}\right)-\sqrt{\frac{E_g-\hbar\omega}{\hbar\Omega_0}}F\left(\frac{E_g-\hbar\omega}{\hbar\Omega_0}\right)\right)$$

$$F(\eta) = \pi[A_i'^2(\eta) - \eta A_i^2(\eta)]$$

$$G(\eta) = \pi[A_i'(\eta)B_i'(\eta) - \eta A_i(\eta)B_i(\eta)]$$

Shen & Pollak, Phys. Rev. B 42, 7097 (1990)

Photo-reflectance

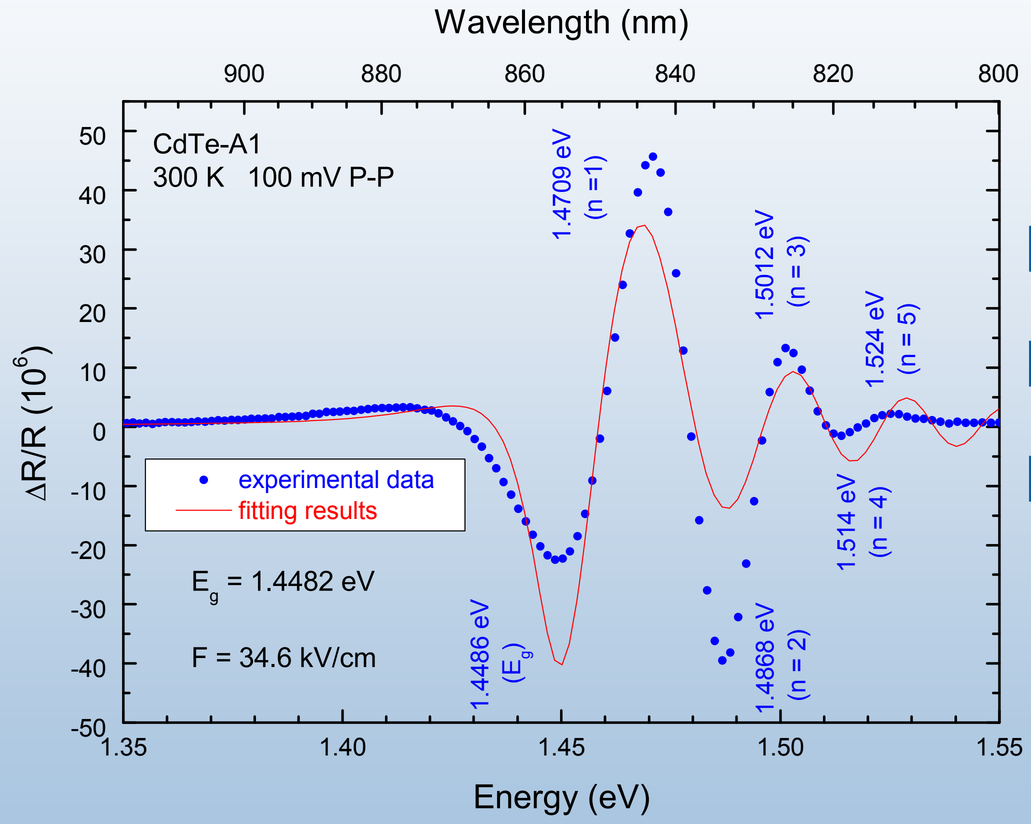


From Data fitting :

E_{max} = 31.9 kV/cm

E_g = 1.448 eV

Electro-reflectance

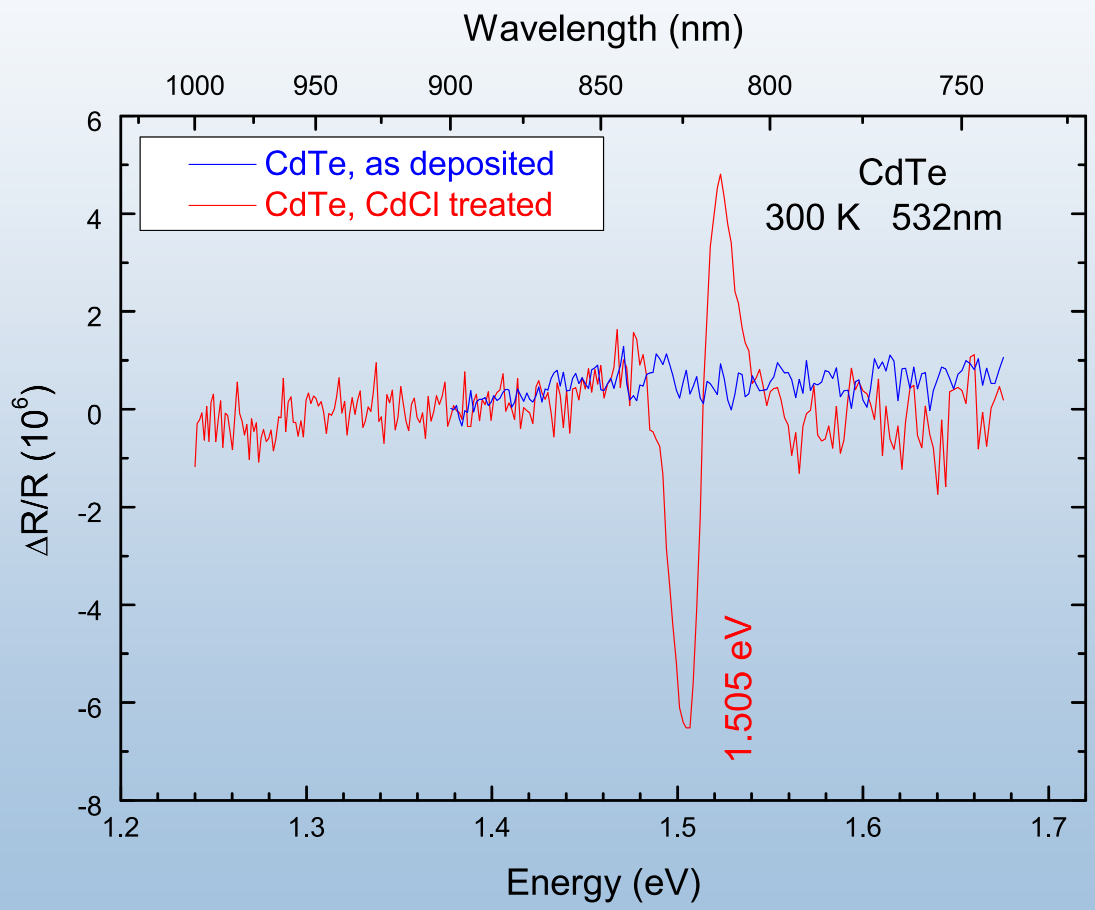


From Data fitting :

E_{max} = 34.6 kV/cm

E_g = 1.4482 eV

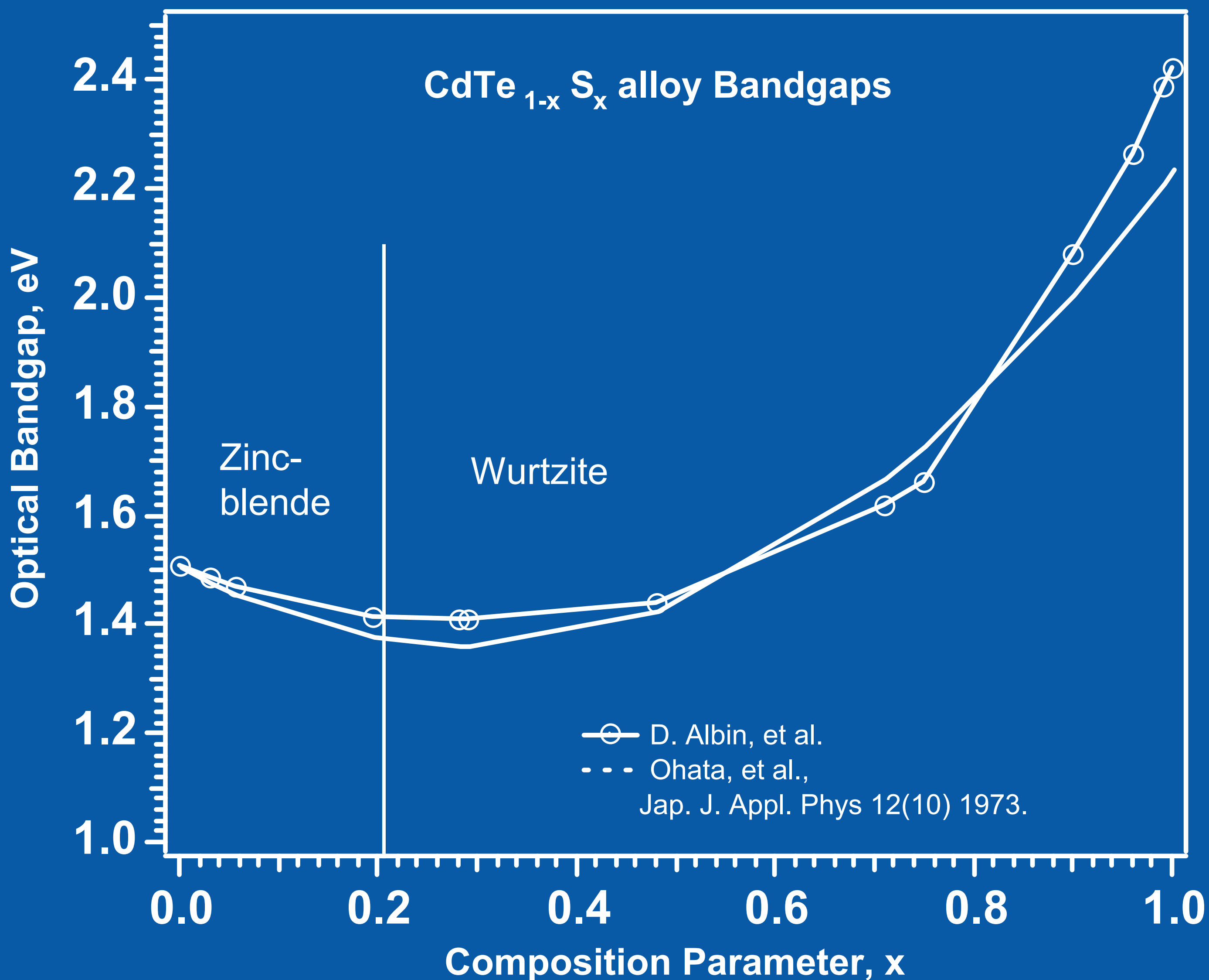
Effect of $CdCl_2$ treatment (by PR)



Modulated Reflectance

- Modulated electro-reflectance and photo-reflectance studies identify a region of high electric field (~32-35 kV/cm) for high efficiency CdS/CdTe devices. The field is present in the region of 1.45 eV material.
- SnO_2/CdTe devices do not show high field region

The high field region corresponds to Te-rich CdSTe alloy.


CdTe 1-x Sx alloy Bandgaps
Optical Bandgap, eV
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Zinc-
blende
Wurtzite
D. Albin, et al.
Ohata, et al.,
Jap. J. Appl. Phys 12(10) 1973.
0.0
0.2
0.4
0.6
0.8
1.0
Composition Parameter, x

From E_{max} = 32 kV and

depletion width on p-side = 3 μm (base on C-V and EBIC results)

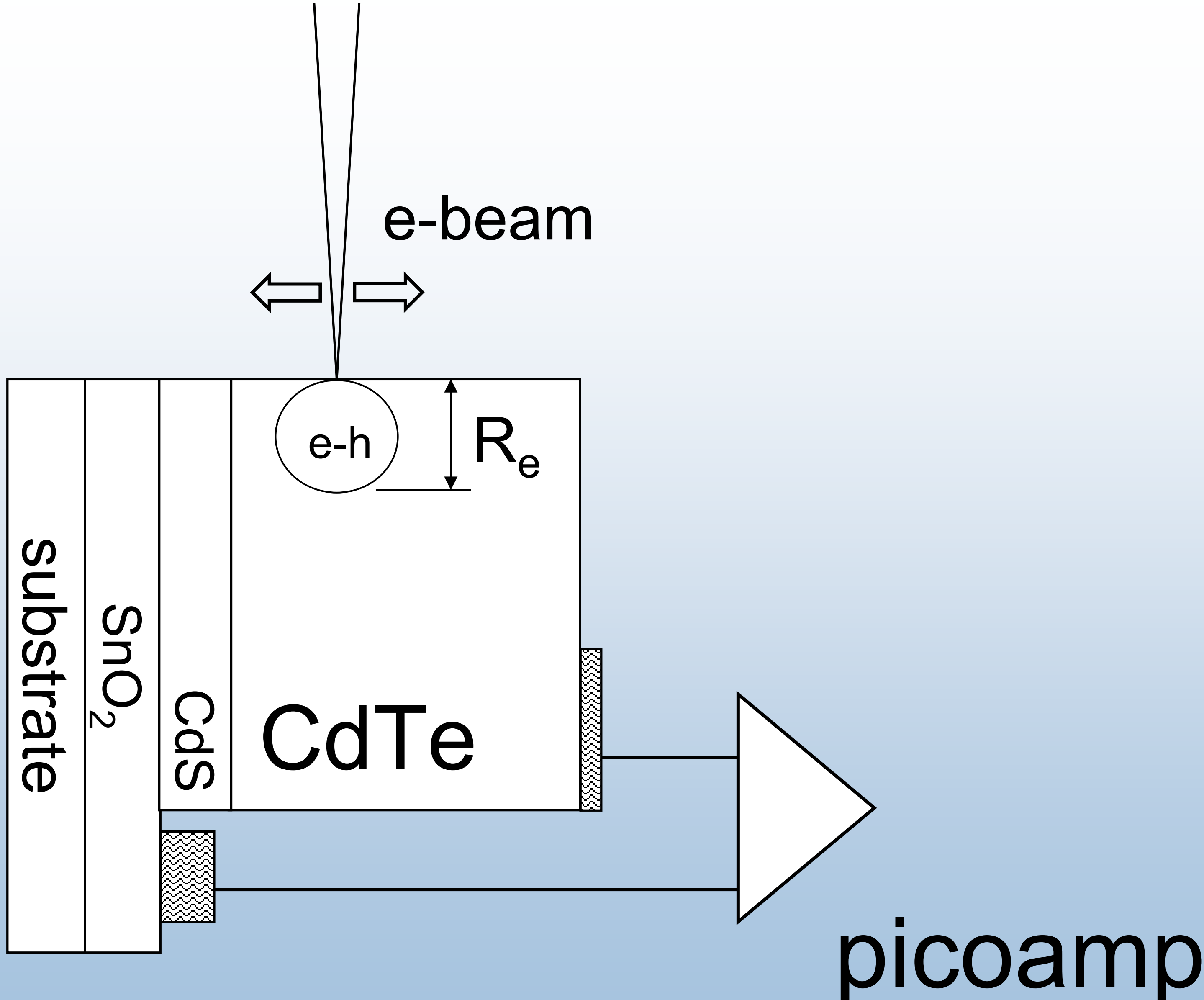
Using $E_{max} = qN_A X_p/\varepsilon_s$

Gives $N_A = 5.5\text{x}10^{14}$ cm^{-3}

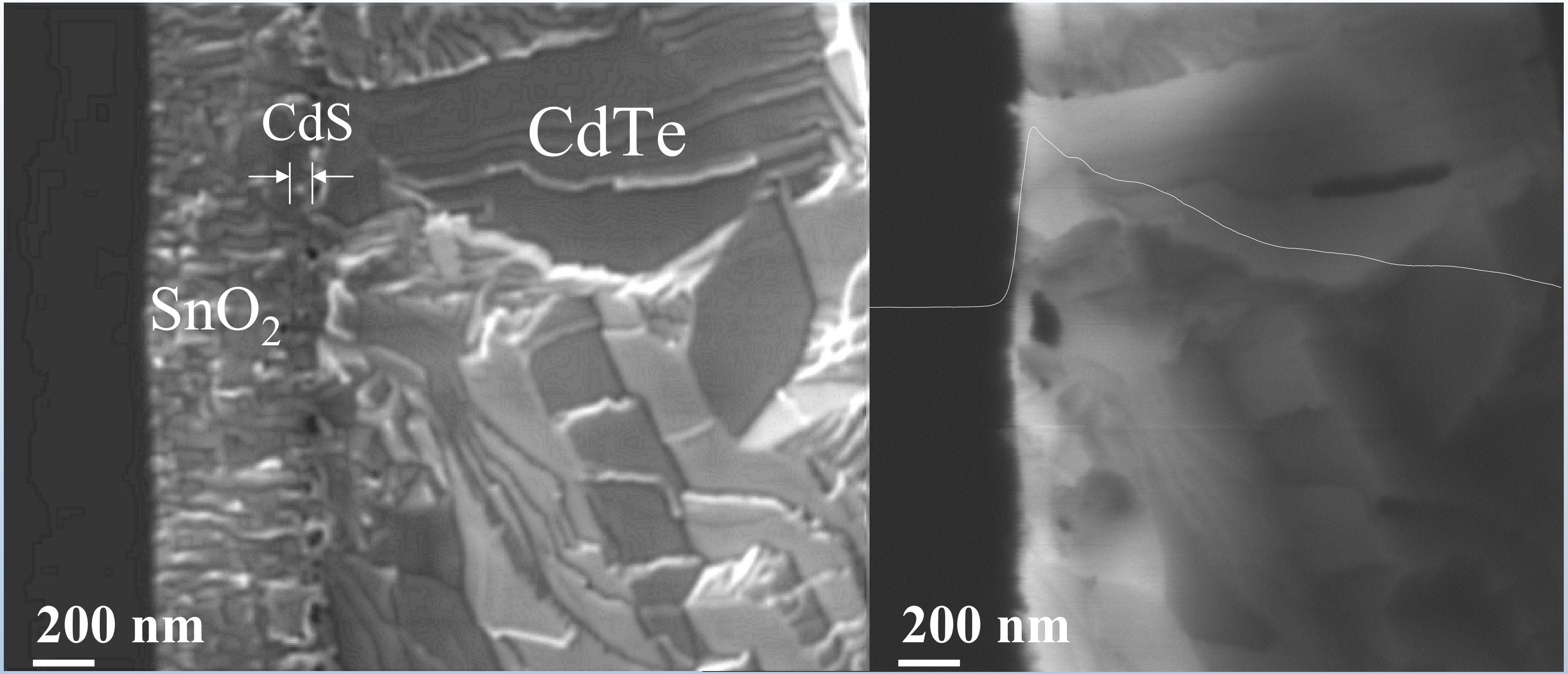
Evaluation of N_D based on SIMS and EBIC results

EBIC

- SEM and HR-EBIC measurements performed on high V_{oc} (835 mV) device.
- Measurements on the cross-section of the device. Shows EBIC response close to CdS/CdTe interface.

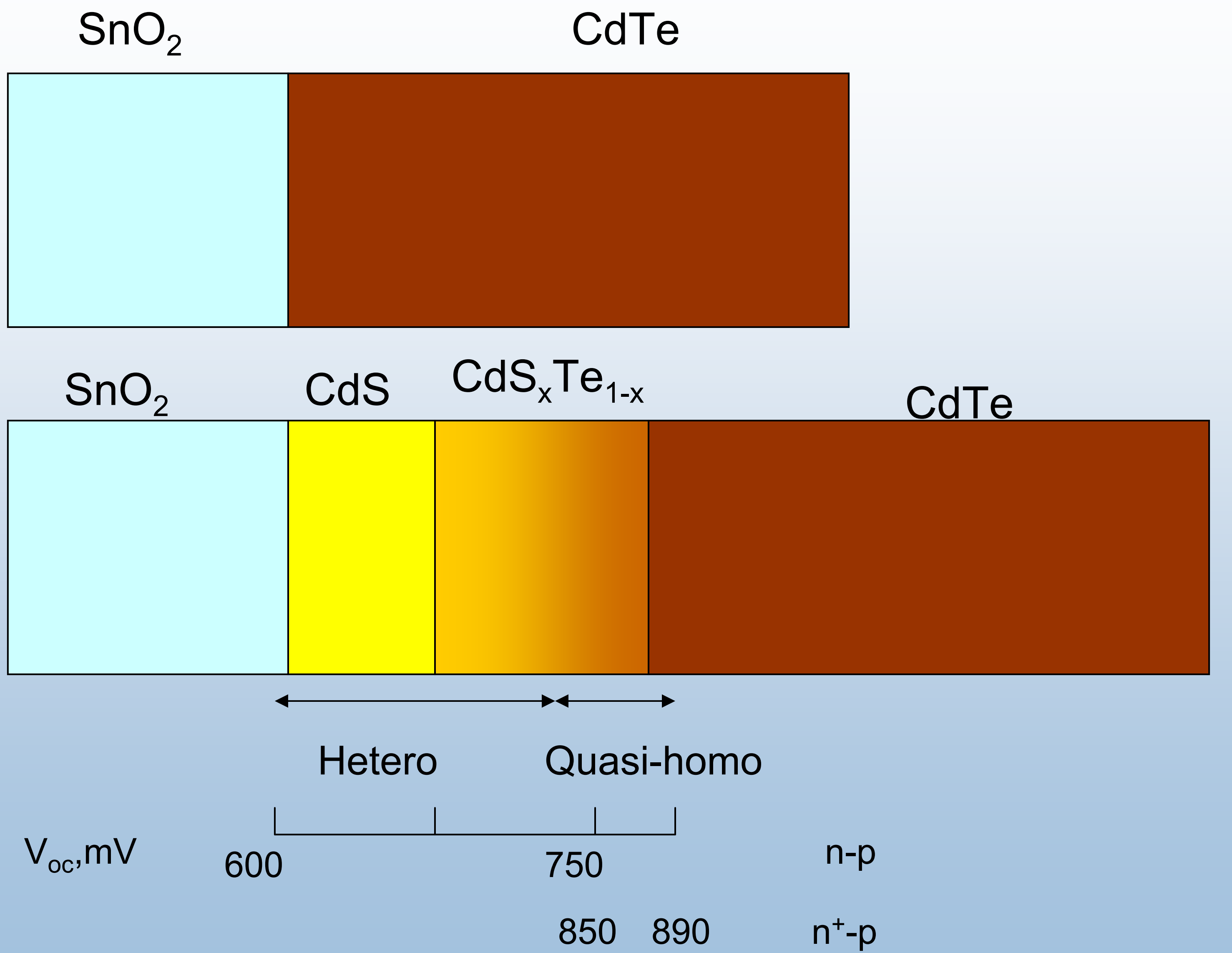

e-beam
e-h
R_e
substrate
SnO_2
CdS
CdTe
picoamp

Electron-beam-induced-current



HREBIC

Device model



Device structure	V_{oc}, mV
SnO_2/CdTe	600-650
CdS/CdTe as dep	720-750
CdS/CdTe w/ $CdCl_2$	840-850

- Lower V_{oc} devices are true hetero-junctions, whereas the devices with CdCl2 treatment have a junction between n^+ Te-rich CdSTe alloy (doped with Cl) and p-type CdTe with compatible cubic structure i.e. quasi-homojunction.

- A true hetero-junction CdS/CdTe device performance will be dominated by interface defects at the hetero-interface which will be within the depletion region. This may be the case for as deposited devices fabricated at lower temperatures and SnO_2/CdTe devices giving low Voc.

- Role of CdS is mainly to produce Te rich alloy layer that gets doped to n-type during $CdCl_2$ process and passivation of the surface.