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National Renewable Energy Laboratory

Innovation for Our Energy Future

Crystallization of a-Si for solar cell applications

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National Renewable Energy Laboratory

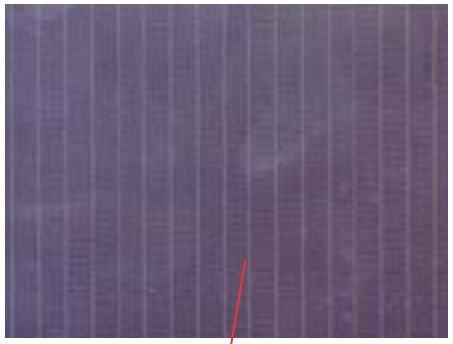
May 19, 2005, a-Si national team meeting, Golden, CO, USA

NREL is operated by Midwest Research Institute • Battelle

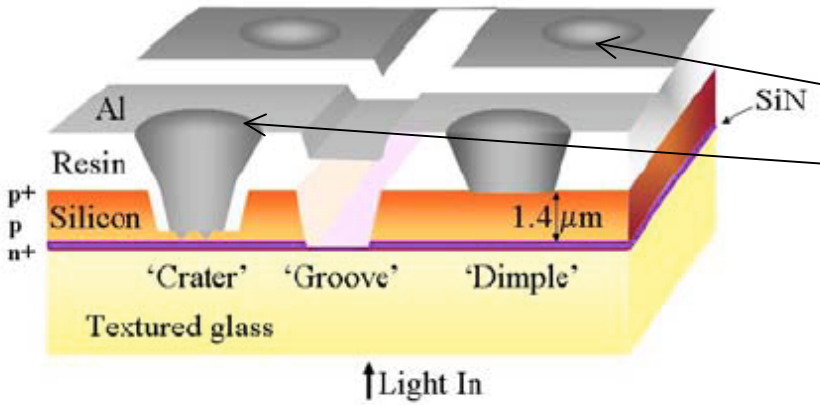
Outline

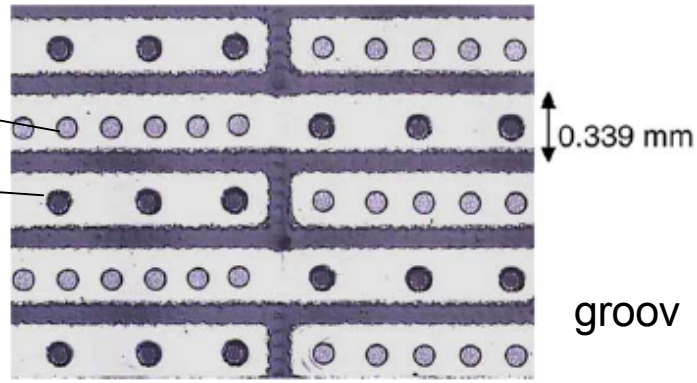
- Solid phase crystallization of a-Si:H on glass
  - Crystal Si on glass module gets 8-9% over 0.7 m^2 (CSG). Absorber: p^-
  - SPC cell gets over 9% (Sanyo). Absorber: n^-
  - STAR cell gets 9.8% (Keneka). Absorber: *i*
- Crystallization of hot-wire a-Si:H
- Epi-Si on seed layer -> 15% ?
  - Seed layers
    - CeO_2 and other foreign coatings (NREL)
    - Metal induced Si seeds (hmi, UNSW)
  - Solid phase epitaxy on c-Si
    - In-situ monitoring for kinetics

CSG Solar's cells



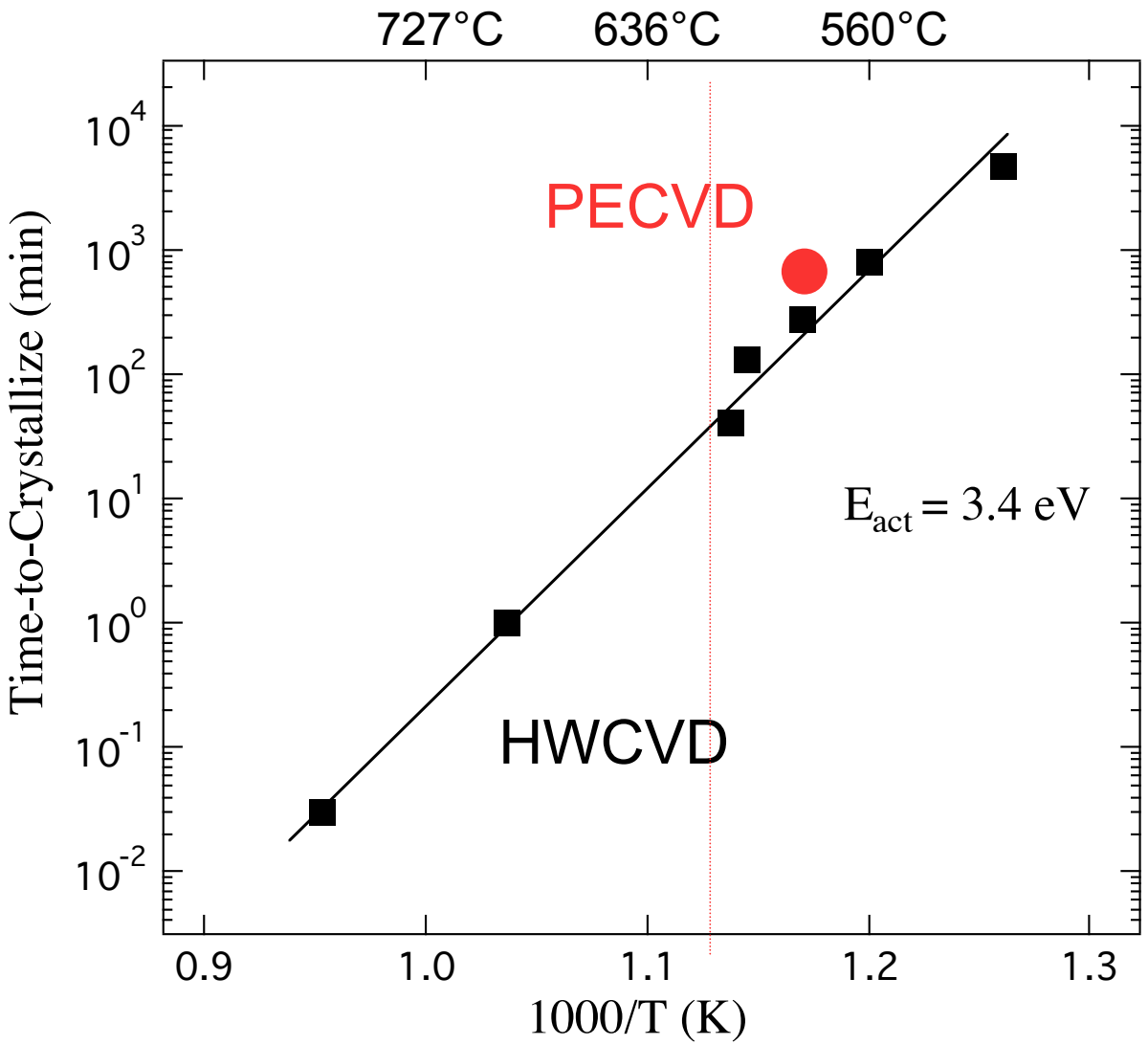
Cell thickness: < 2 μm
Eff: 8-9%
Borofloat glass substrate





www.csgsolar.com

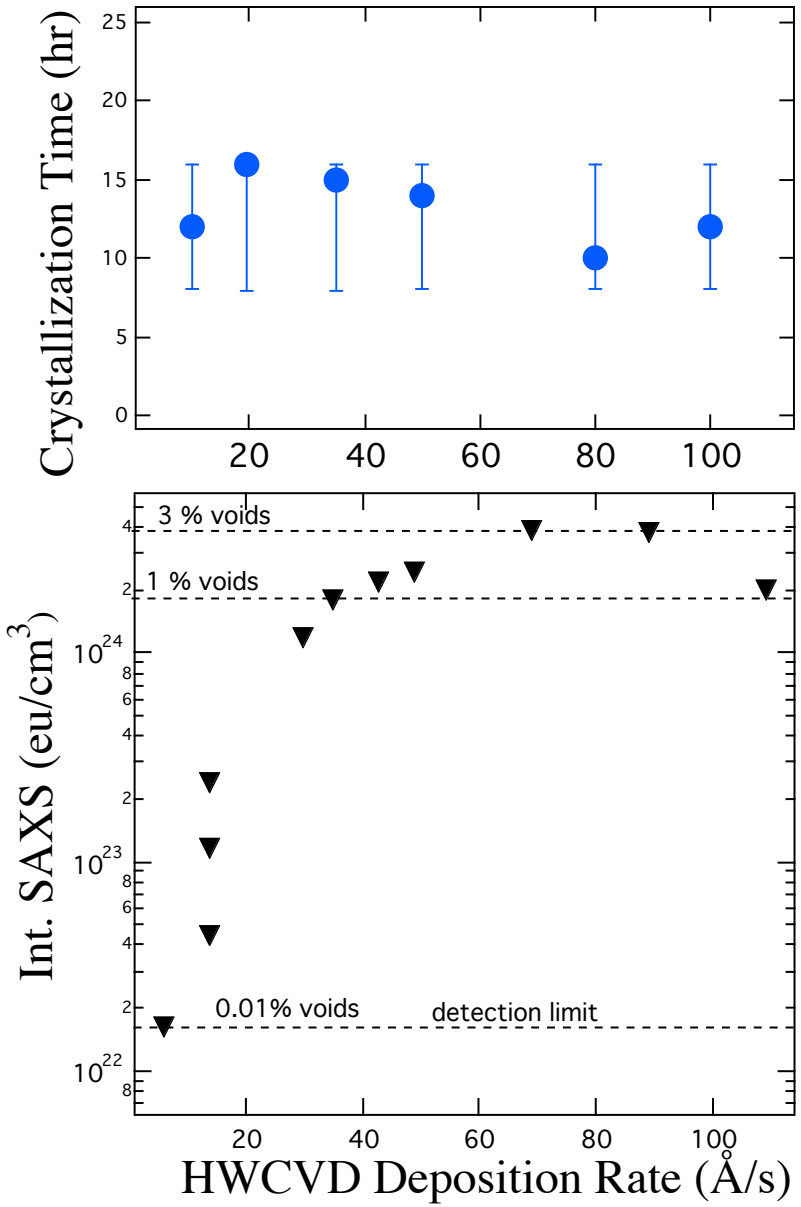
High Activation Energy of Crystallization Time



NREL HWCVD

- E_{act} = 3.4 eV
- Independent of film thickness (0.3 - 2μm)
- Independent of film deposition rate (10-100 A/s)
- HWCVD ~ 4X faster than PECVD

Crystallization Time Independent of Deposition Rate

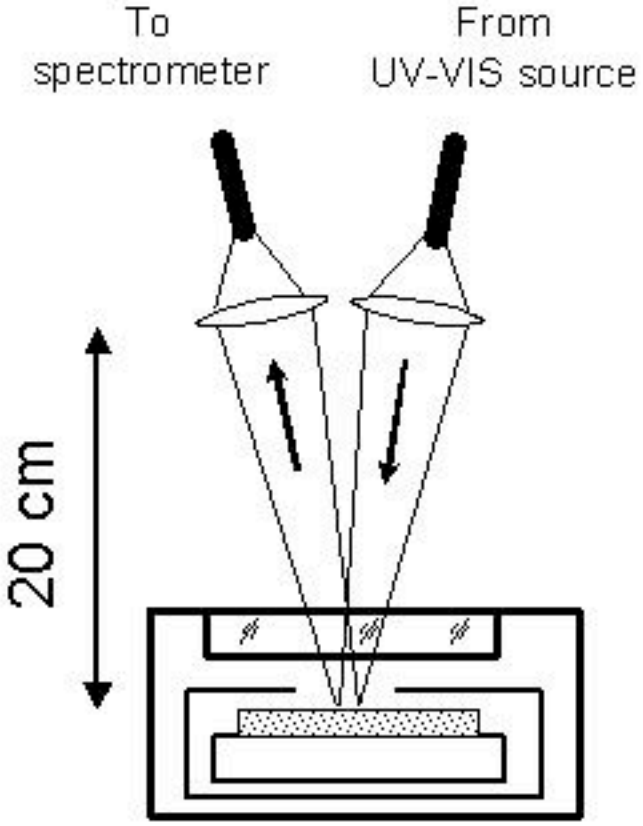


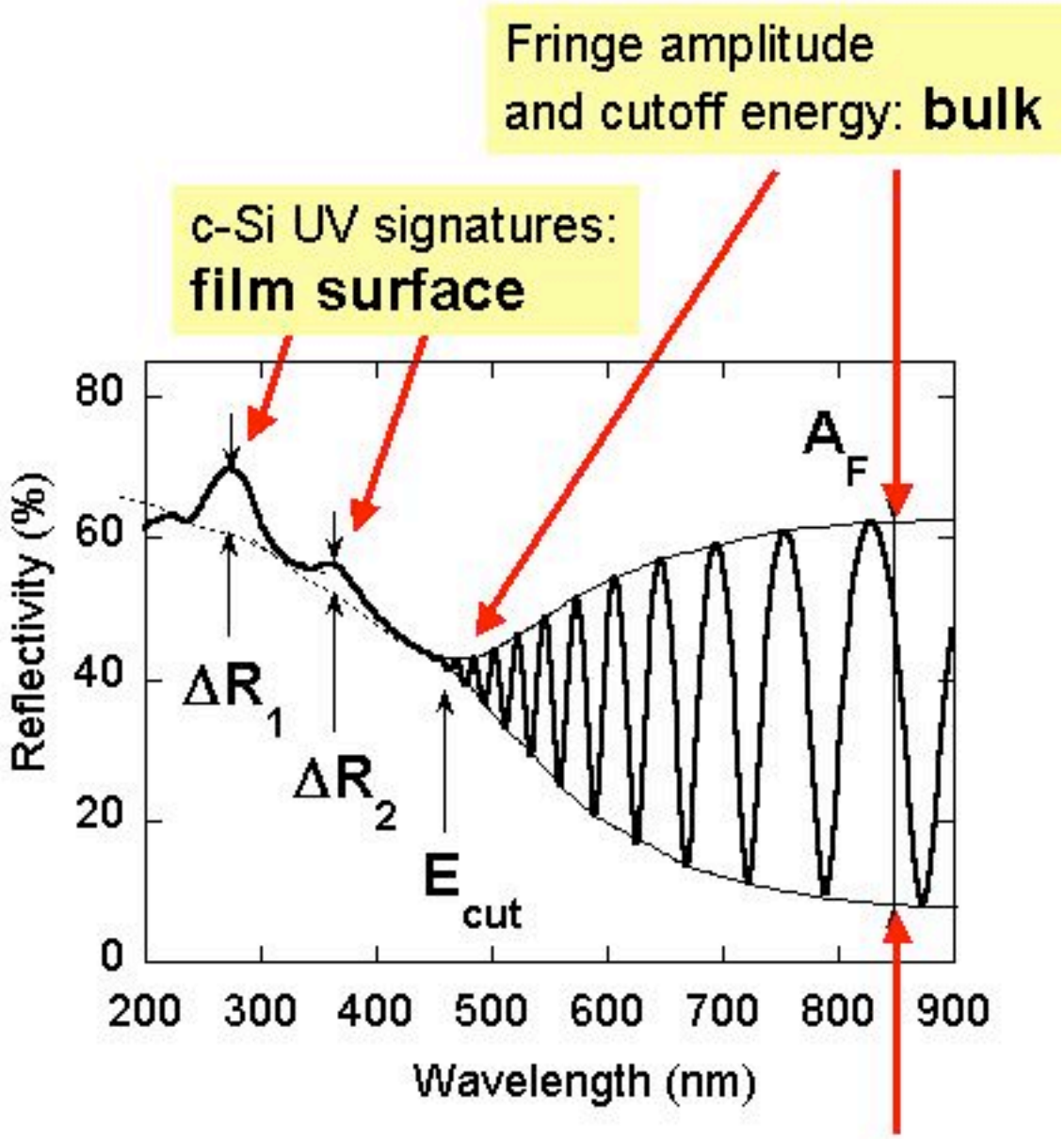
- Crystallization time is constant from 10 - 100 Å/s

- Small angle X-ray scattering (SAXS)
- 100X increase in microvoid density from 10 - 100Å/s
- Microvoid radii 20 - 50 Å
- What happens to the voids after SPC? (under study)

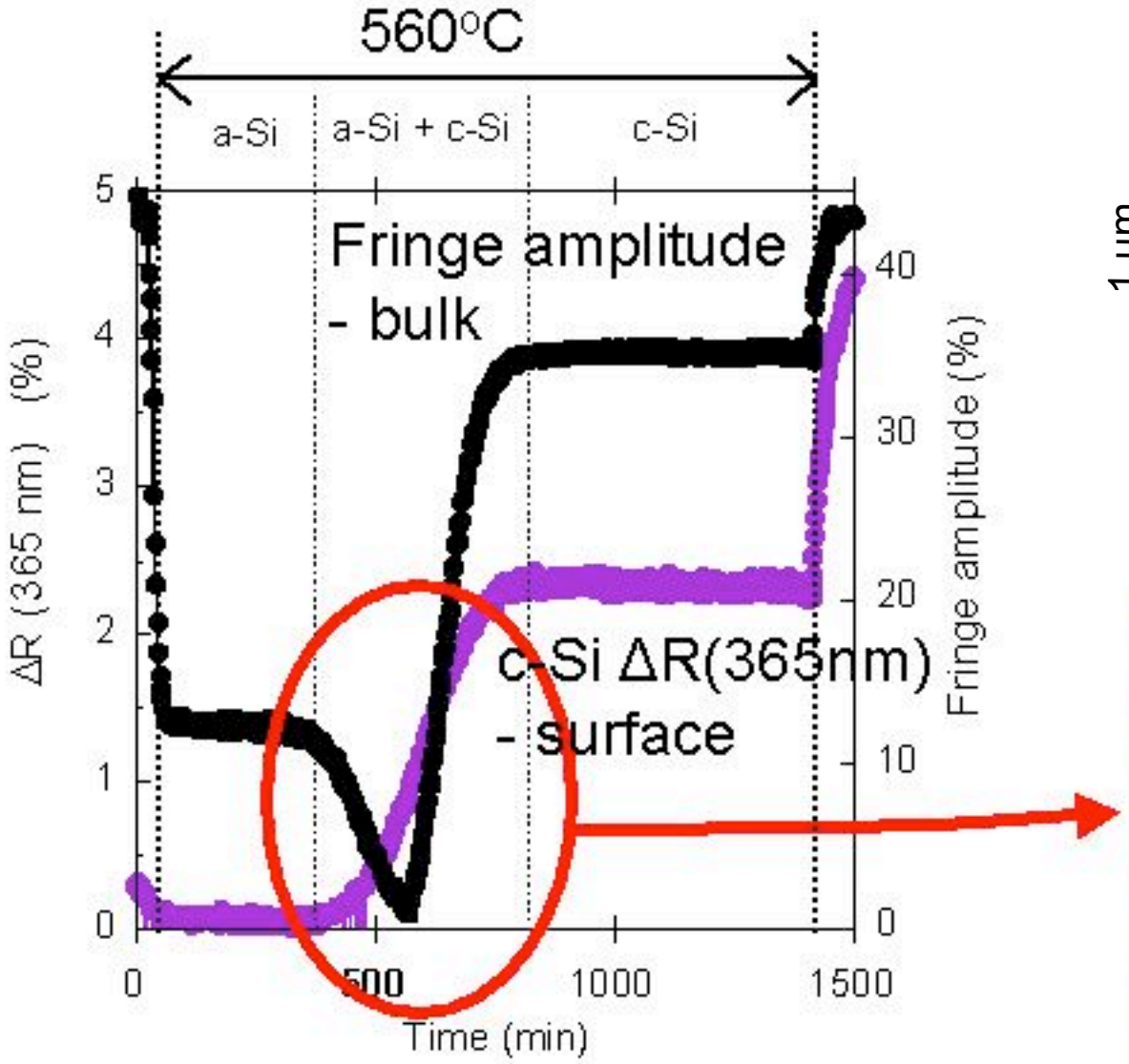
Adapted from A. H. Mahan et al., J of Appl. Phys. **90**, 5038 (2001)

In-situ, real time optical reflectance spectroscopy

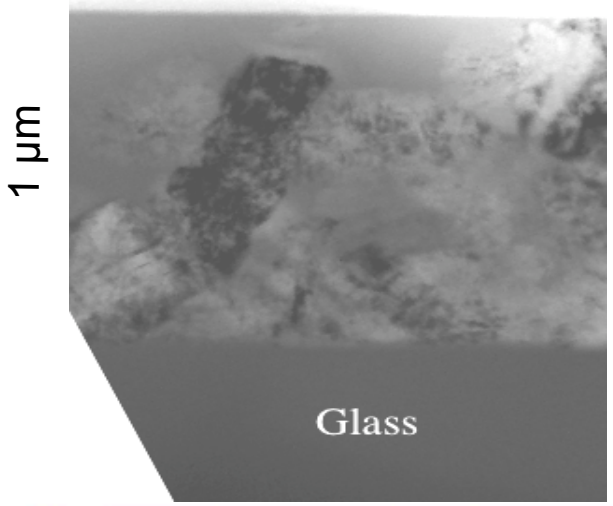




Random crystallization: bulk and surface crystallize at the same time



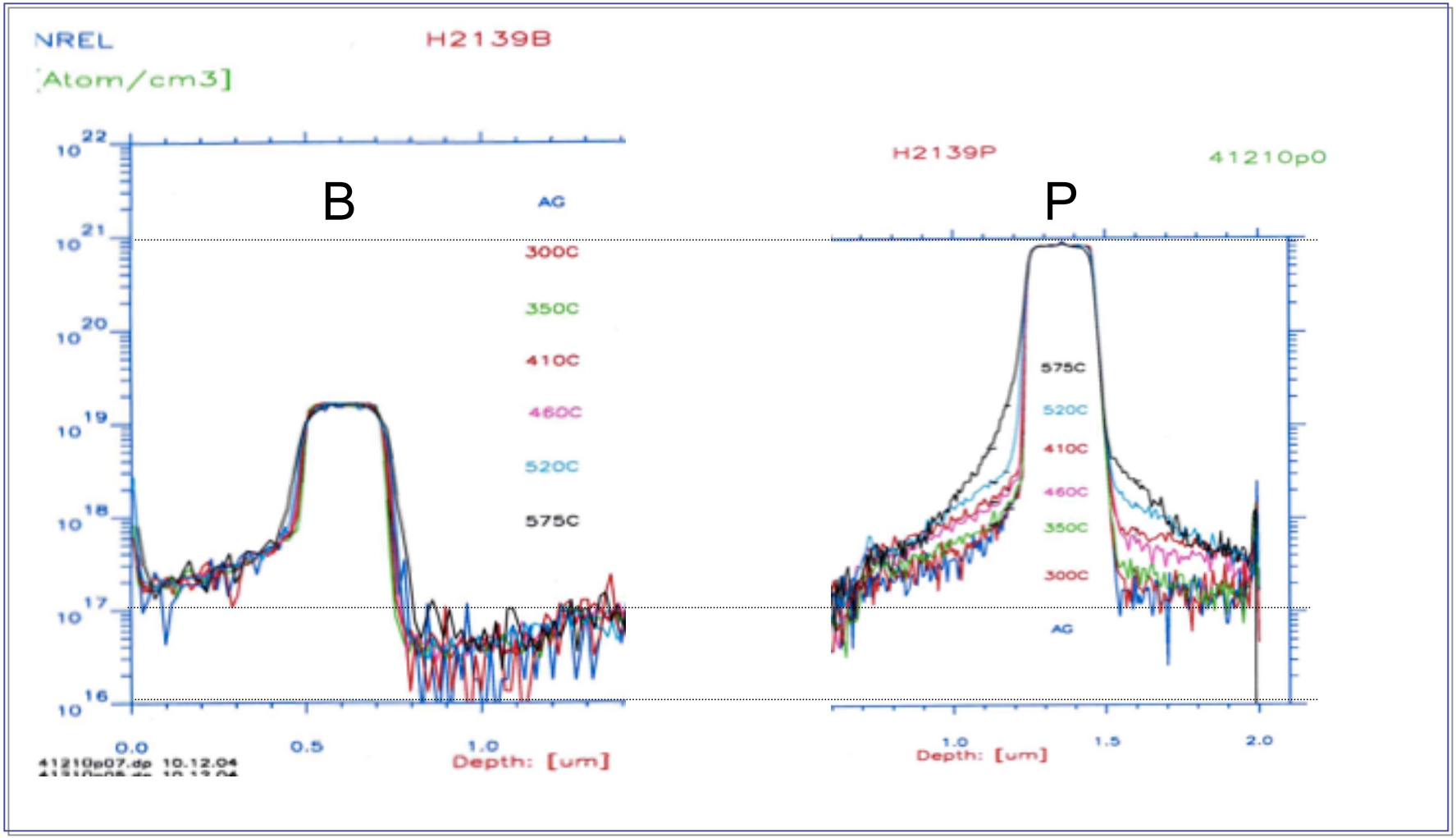
a-Si:H on glass



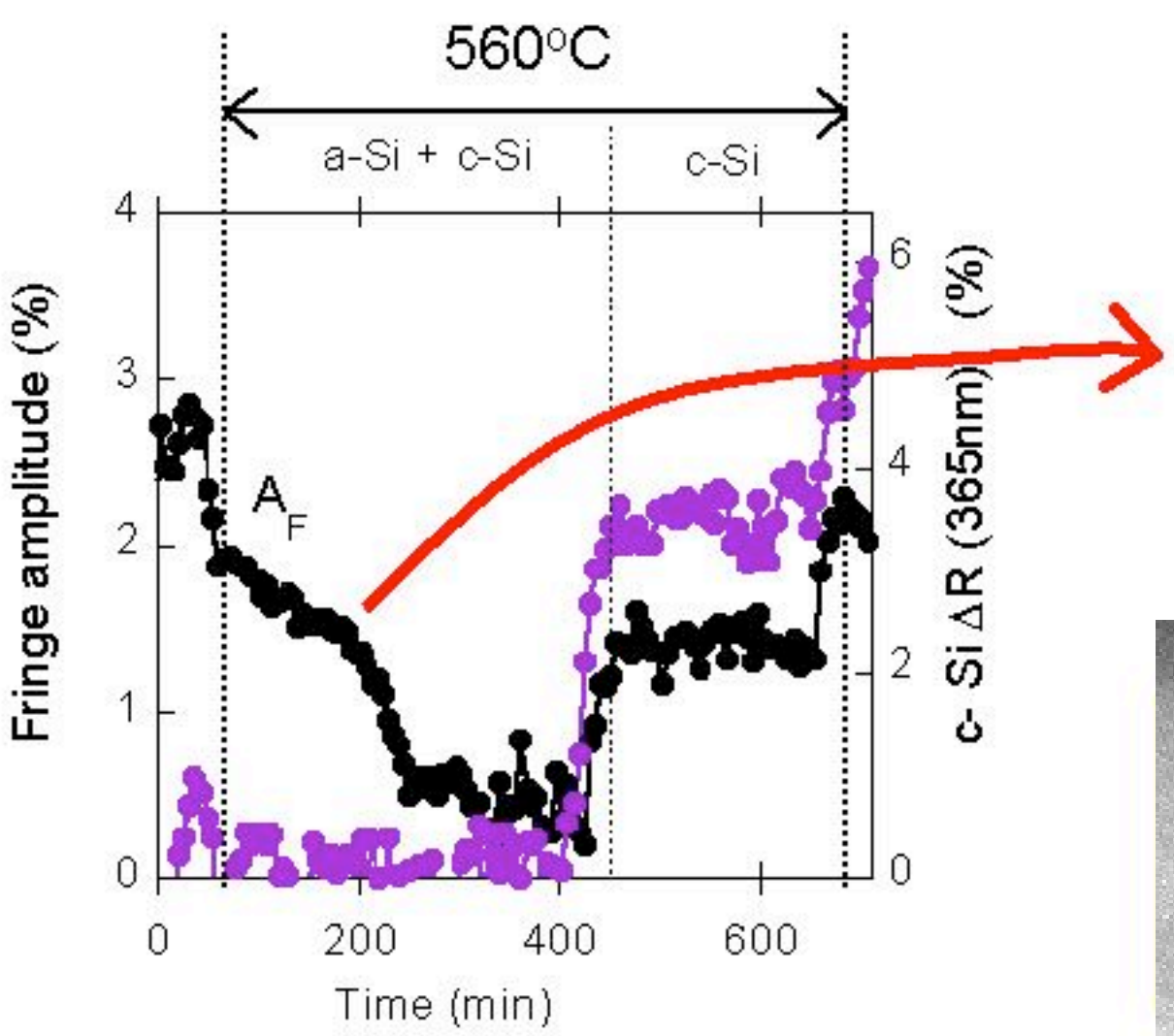
Fringes **collapse** and c-Si UV signatures appear:

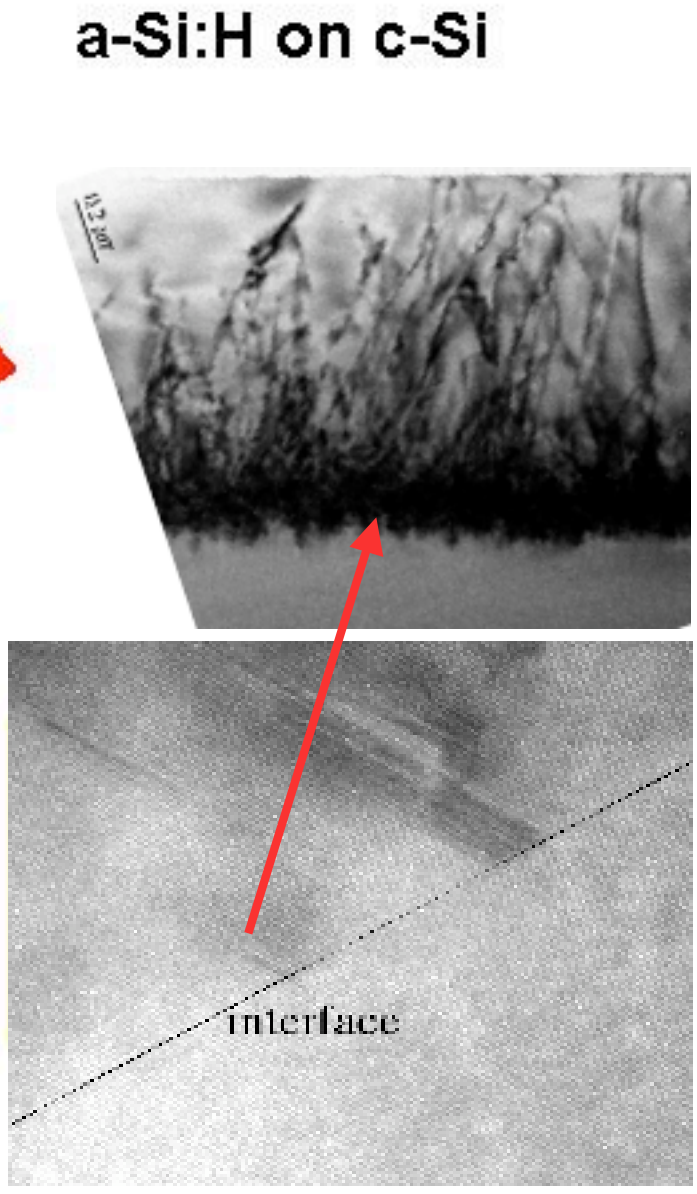
Random nucleation and growth in the bulk

P diffuses more than B during 4 hr anneal

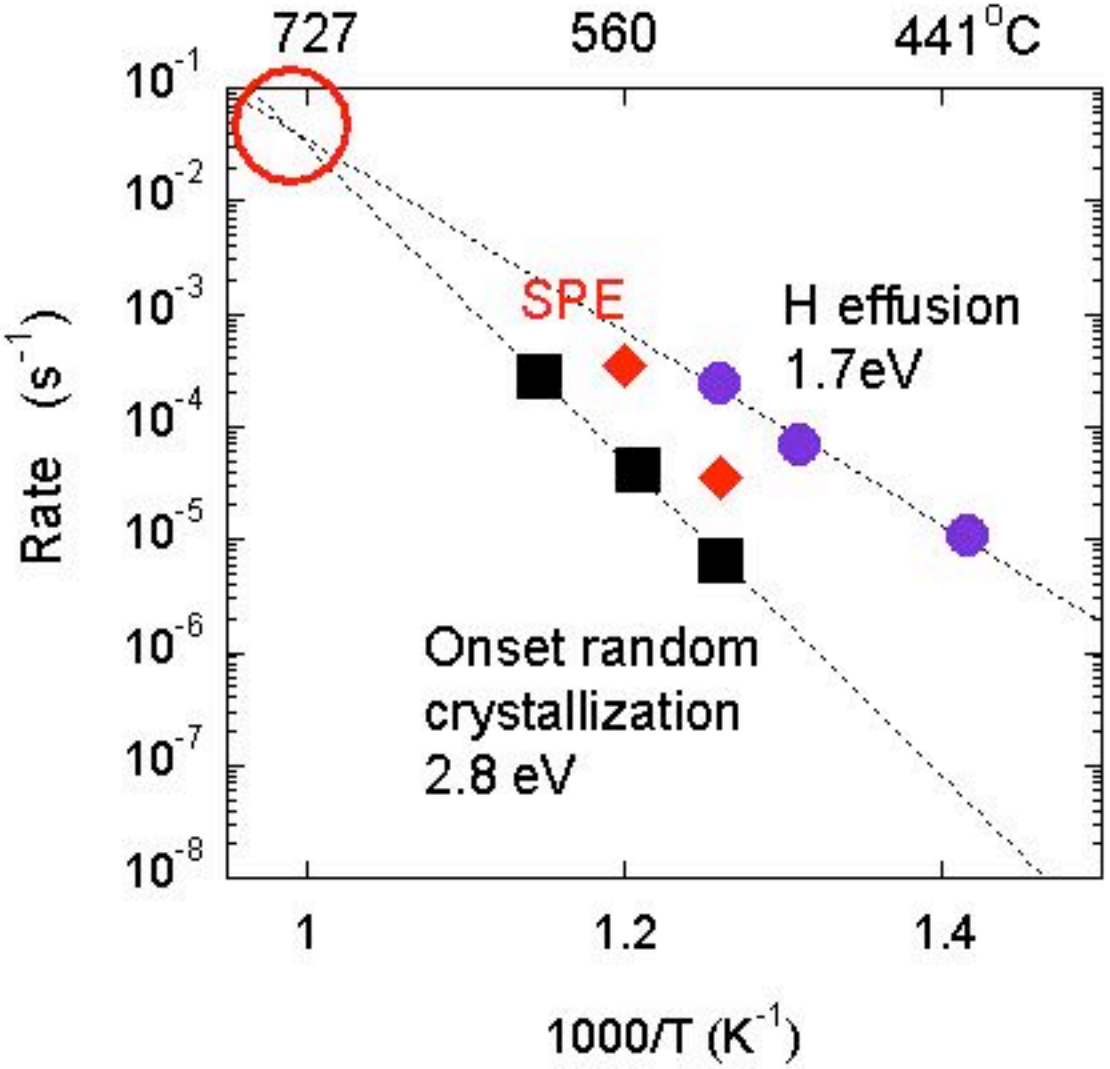


Solid phase epitaxy on c-Si “seed” layer





Temperature – time - thickness window for random crystallization and solid-phase epi



1 micron films:

H effuses fast

SPE faster than random crystallization

Summary

- SPC Si on glass: target η~13%
  - Alternative to µc-Si and tandem cells
  - Crystallization time independent of deposition rate and film thickness
  - SPC of HWCVD film is 4 x faster then PECVD film
- Solid-phase epitaxy: target η~ 15%.
  - Better seed layers
  - Control of epitaxy: in-situ monitoring