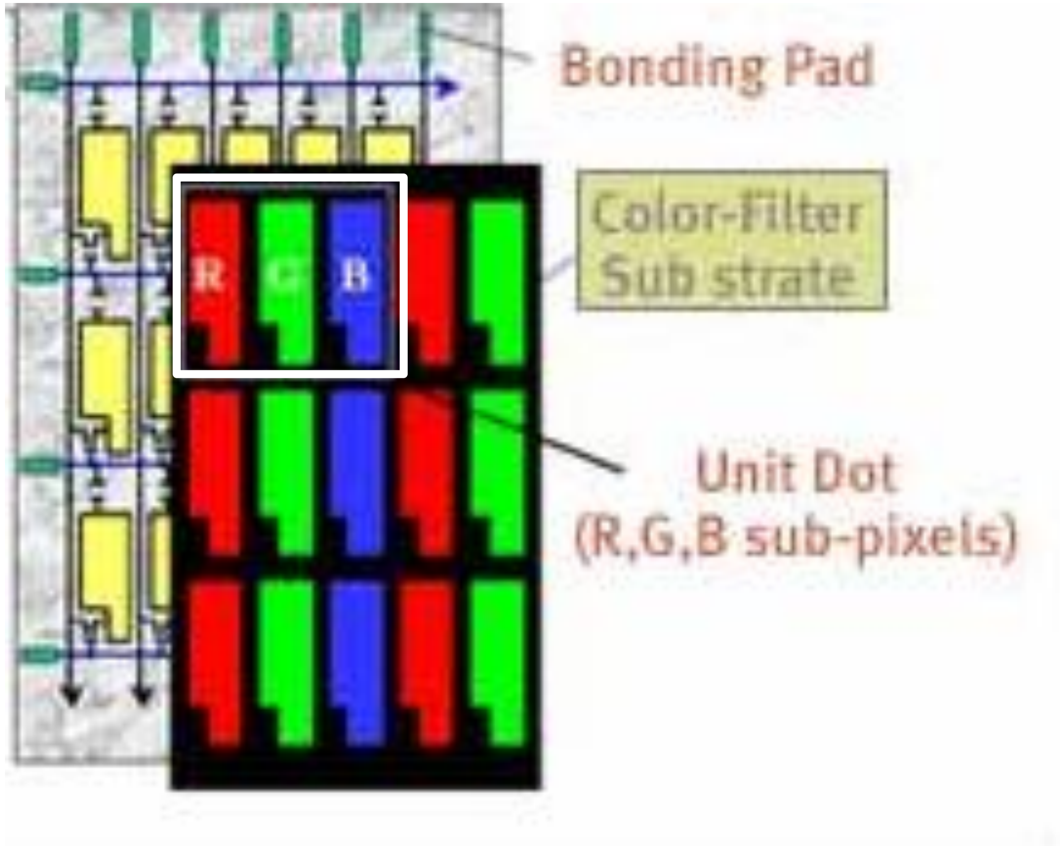
Low temperature polycrystalline silicon (LTPS)

PV-lab
IMT NEUCHATEL

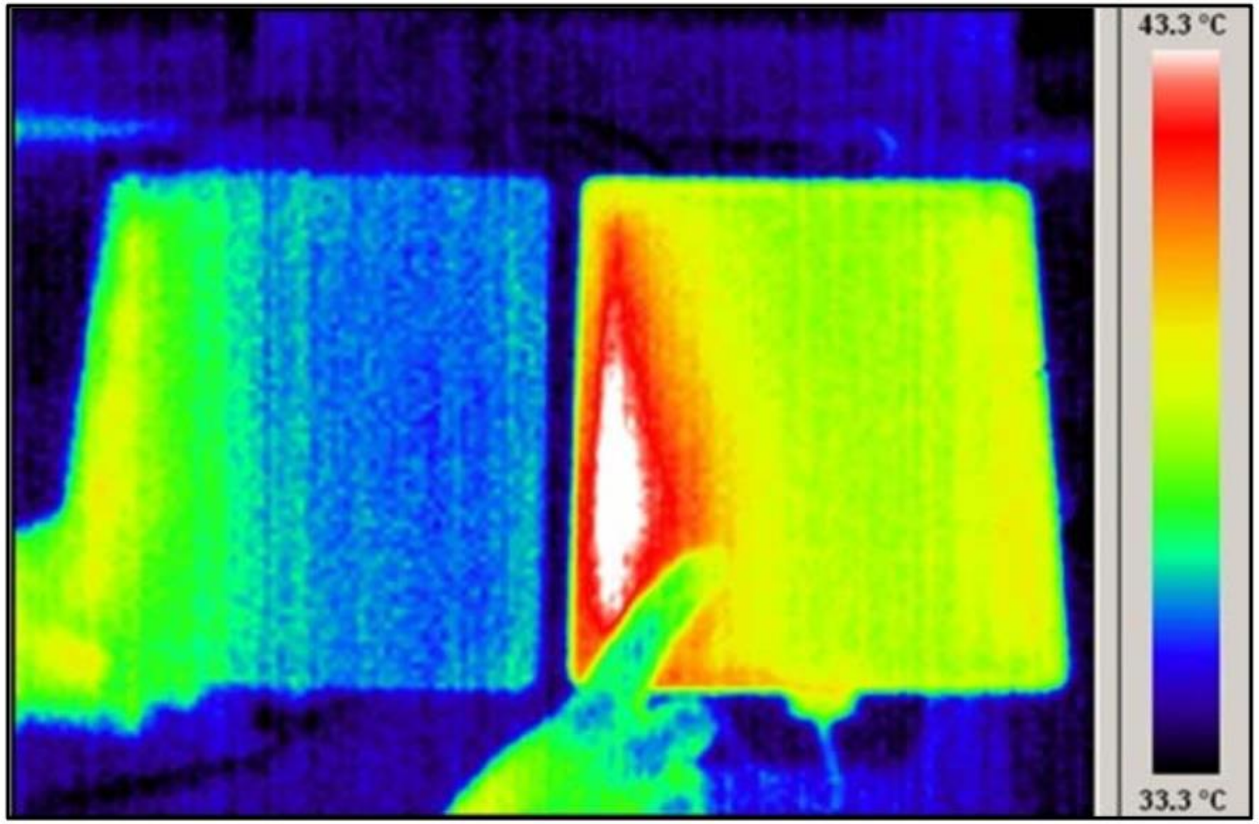
Pixel size



Desktop monitors:
typically 96 to 110 DPI
=> 260 µm pixel size

Phone displays (e.g. retina)
477 DPI (resolution of human eye at 30 cm)
=> 53 µm pixel size

Limitation of a-Si TFT: low channel mobility

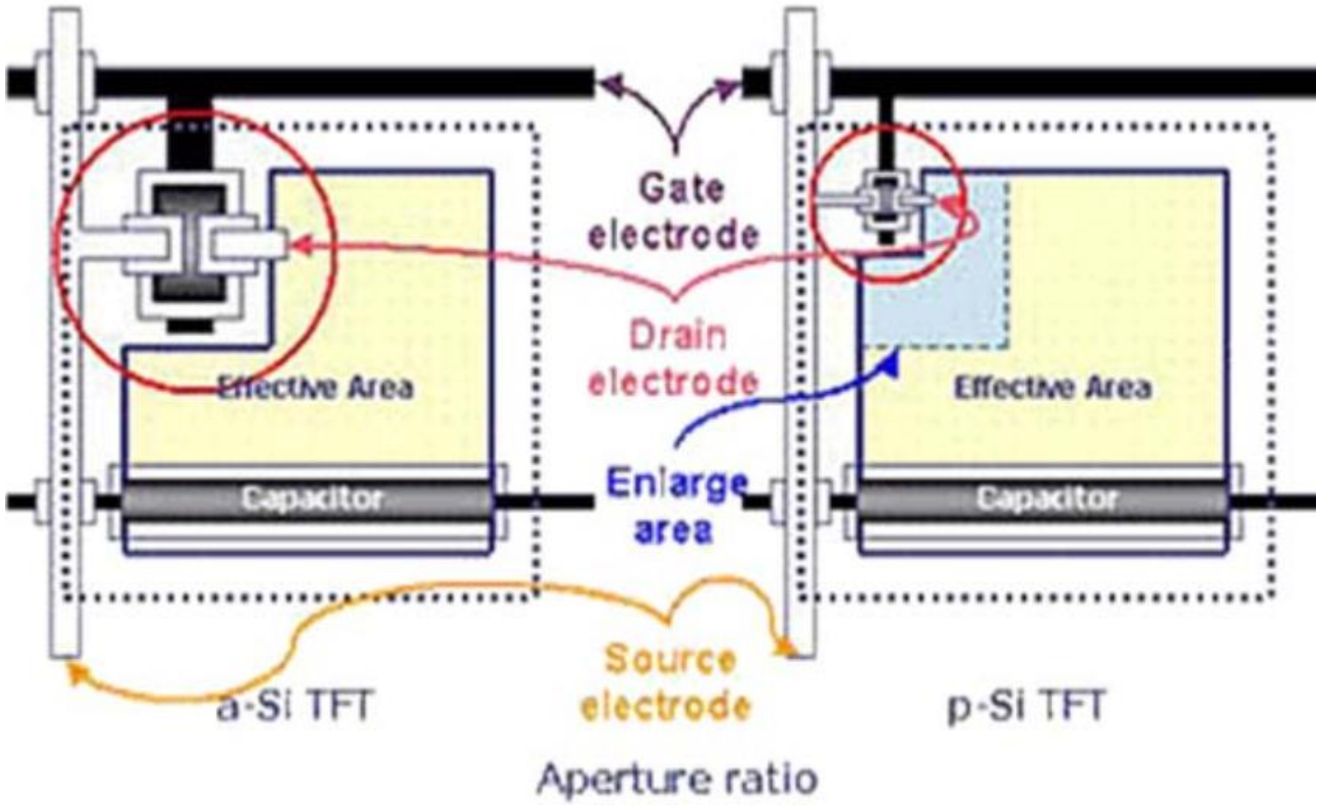


Example: double resolution from iPad2 (1024x768) to iPad3 (2048x1536), smaller pixels, but same a-Si TFT (same size of transistor)
=> smaller effective transmittance of colour pad, needs stronger backlight

source: brochure of COHERENT Inc.

Smaller TFT: needs higher channel mobility

a-Si: $\mu \approx 1 \ldots 10$ cm/Vs LC-Si: $\mu \approx 50 \ldots 400$ cm/Vs



higher mobility: can reduce size of TFT for brighter display with same pixel area, or reduce pixel area for higher resolution

source: brochure of COHERENT Inc.

Low temperature polycrystalline silicon (LTPS)

- deposit a-Si layer
  - PE-CVD films contain H
    => risk of delamination by H_2 release
  - LP-CVD films: deposition at >400°C
    => no plasma & H-free, but challenging for substrates, especially polymers

- Laser anneal
  - UV (e.g. excimer lasers 193-350 nm): shallow absorption, costly systems, but widely used in industry
  - Blue: (e.g. diode laser 440 nm): relatively recent, good absorption in film
  - Green: (e.g. Nd:YAG 532 nm): films partially transparent

Excimer lasers (short for excited dimer)

- Typically noble gas + halogen (actually not dimer but exciplex)
  - ArF (193 nm), KrF (248 nm), XeBr (282 nm), XeCl (308 nm), XeF (351 nm)
  - pump by current pulse (arc plasma, form inversion concentration of bound states)
  - repetition rate Hz to few kHz, emission of ns pulses

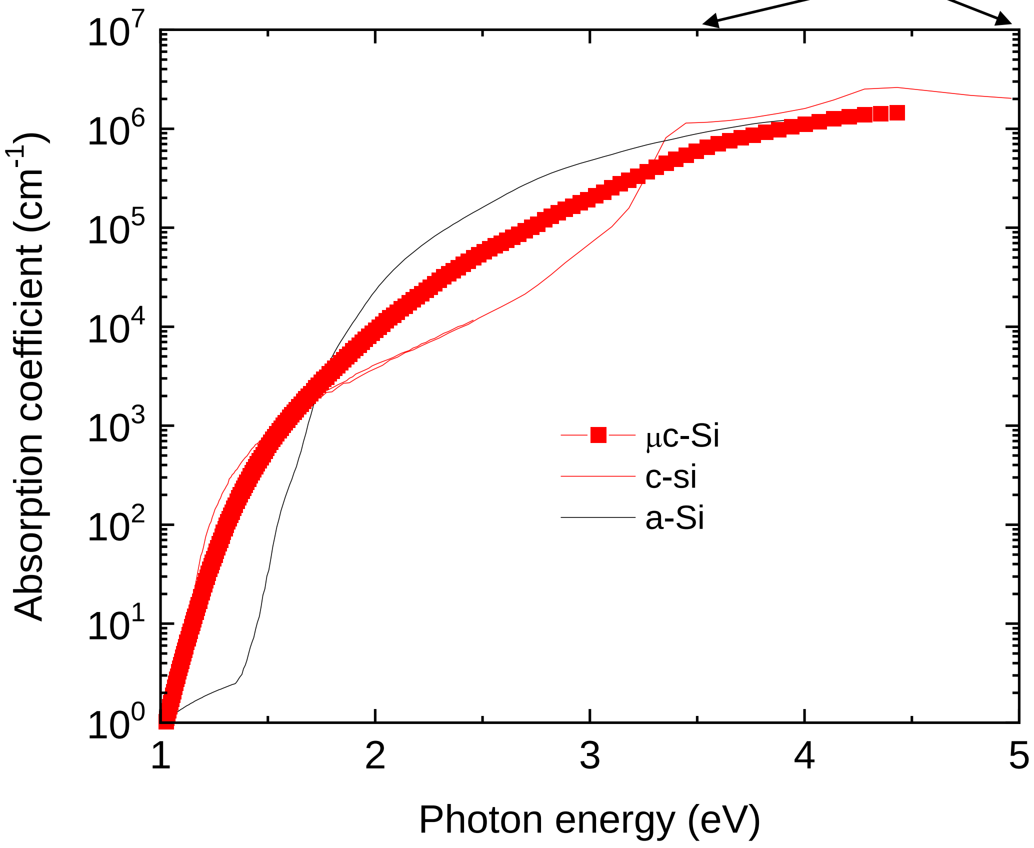
- Costly operation and maintenance
  - contamination of gas mixture
  - wear of tubes by corrosive plasma

- Beam profile
  - large band width
  - poor profile

Absorption length

F.-J. Haug

ArF (193 nm), KrF (248 nm), XeBr (282 nm), XeCl (308 nm), XeF (351 nm)



Lamert Beer law: $I = I_0 e^{-\alpha d}$

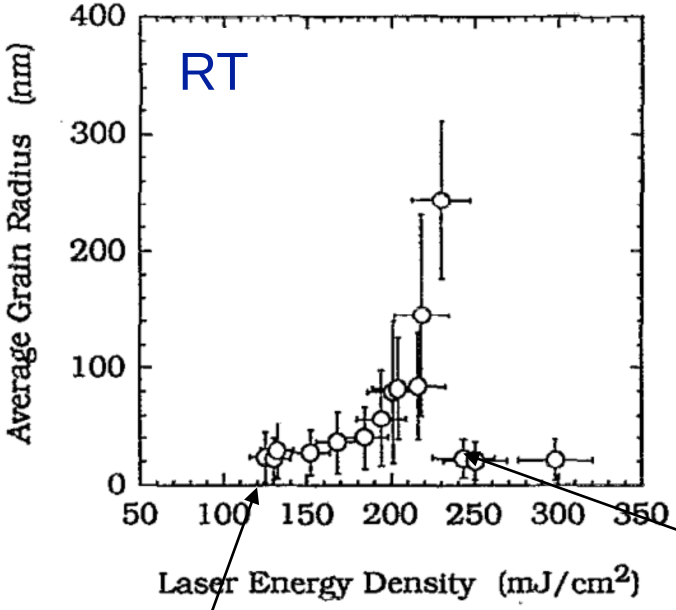
define absorption length by $\alpha d = 1$

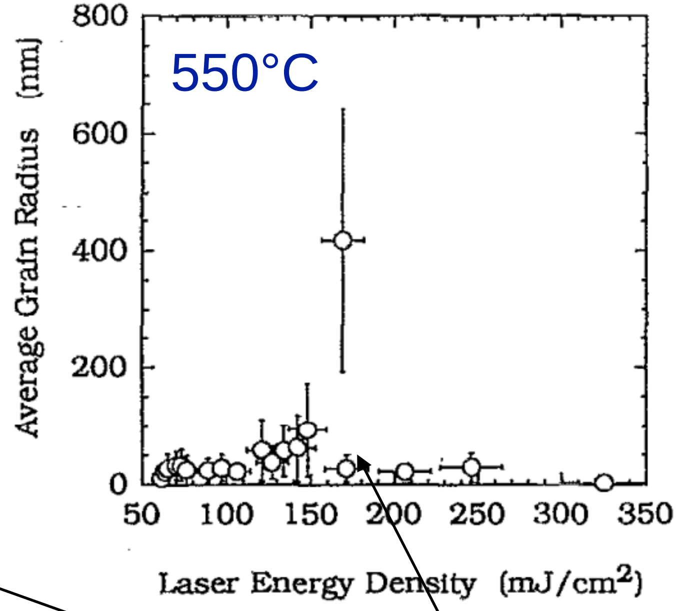
(decay to 36%)

for $\alpha = 10^6$ cm^{-1} and RT: $d \approx 10$ nm

(regardless whether a-Si or c-Si)

Impact of laser fluence





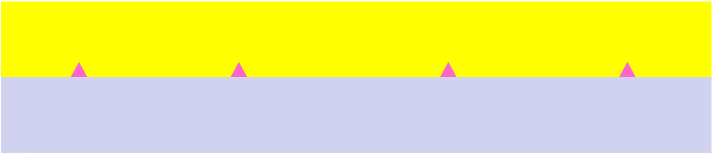
Note: larger grains
on heated substrate
(slower quenching of liquid)

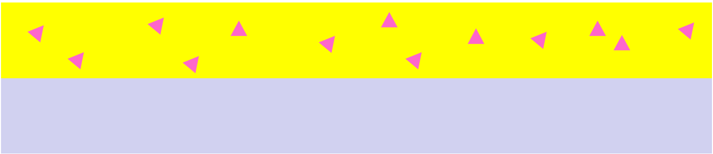
crystallization threshold

- melt most of film
- crystallize liquid from seeds at interface

amorphization threshold

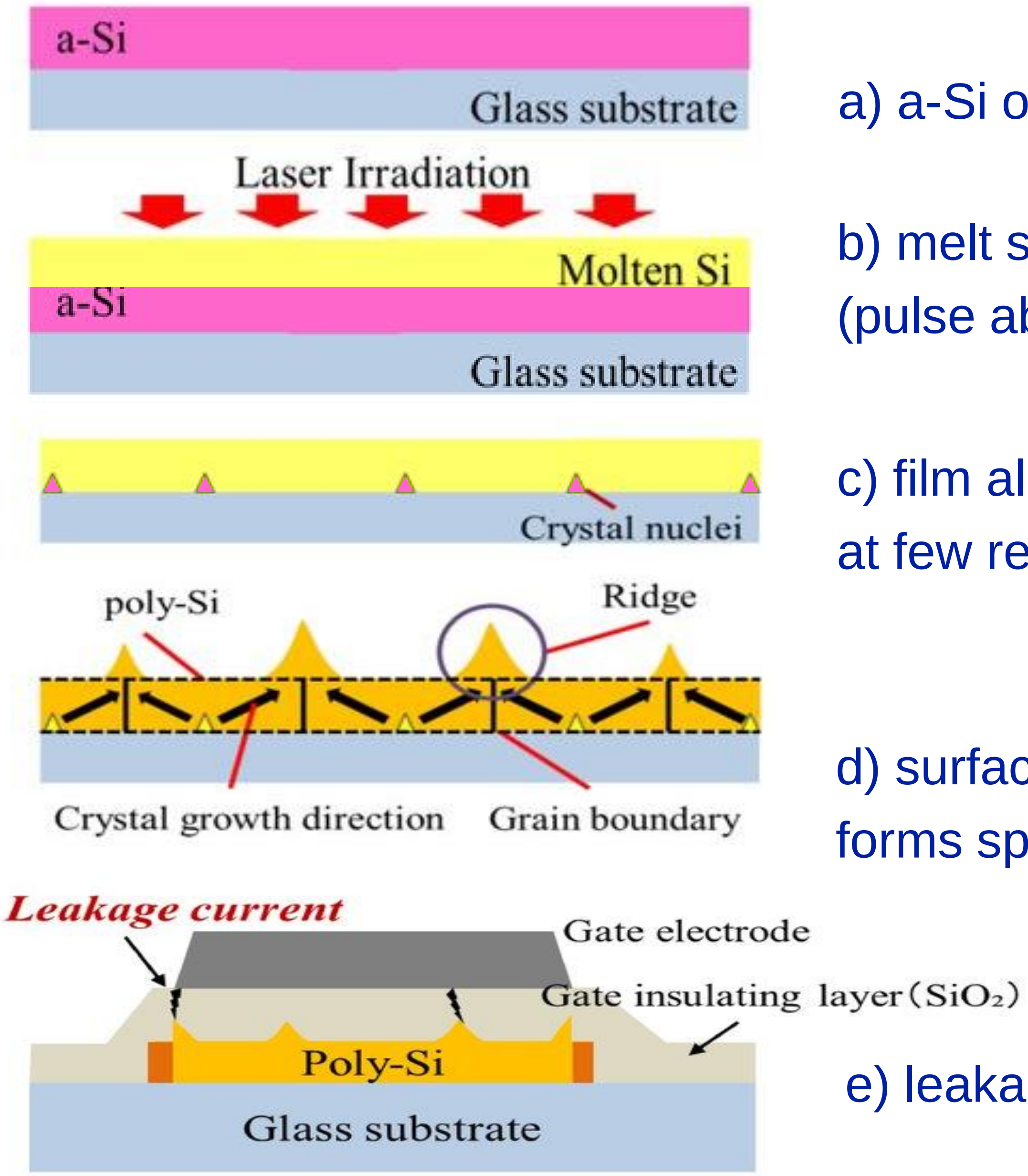
- melt film completely
- supercool, crystallize from random seeds





Im, APL (1993)

Grain growth model



a) a-Si on glass

b) melt starting from front
(pulse absorbed near surface)

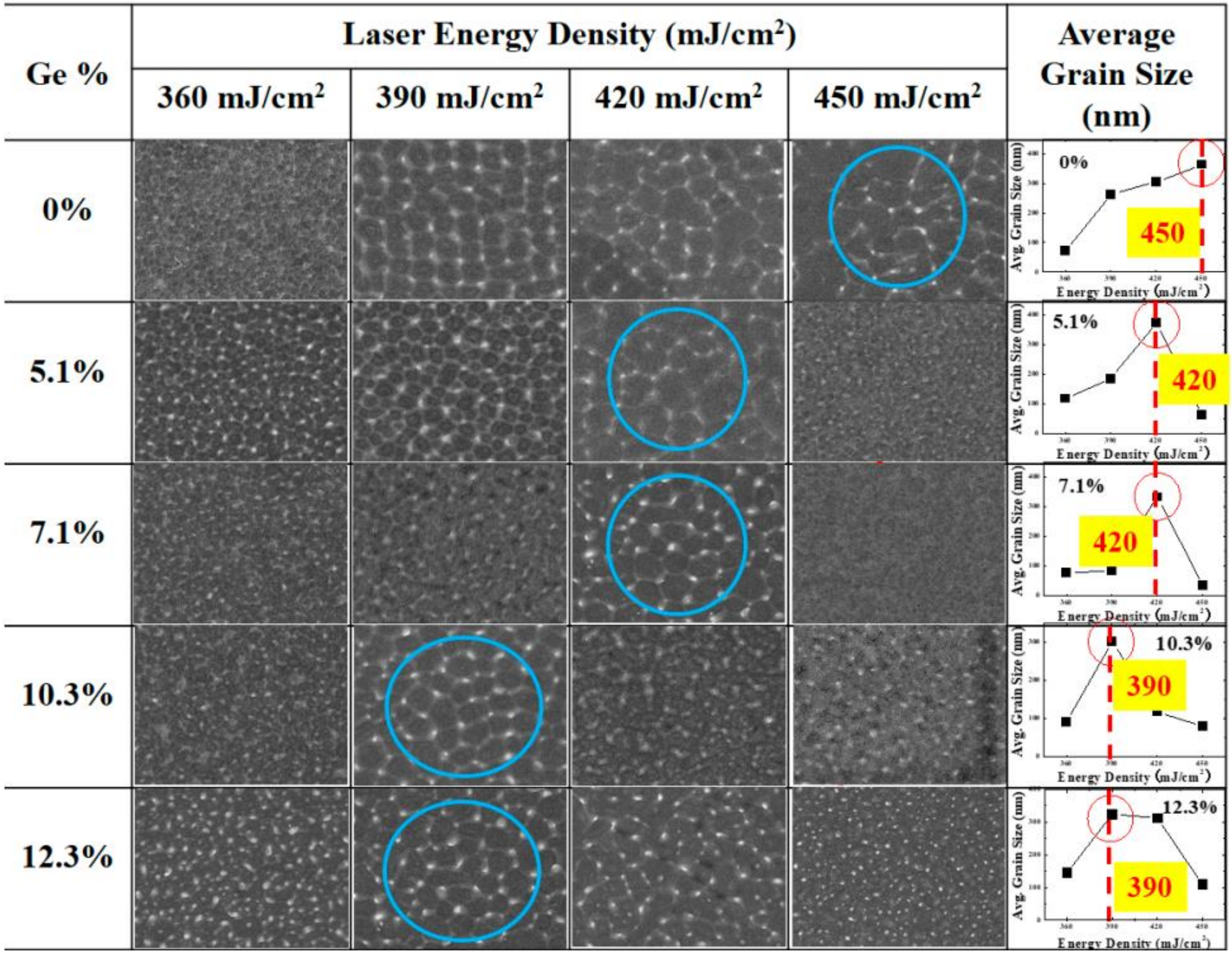
c) film almost fully liquid, nucleation
at few remaining proto-crystals

d) surface tension
forms spikes at GBs

e) leakage issue by spiking

Hamano, Proc. SPIE (2020)

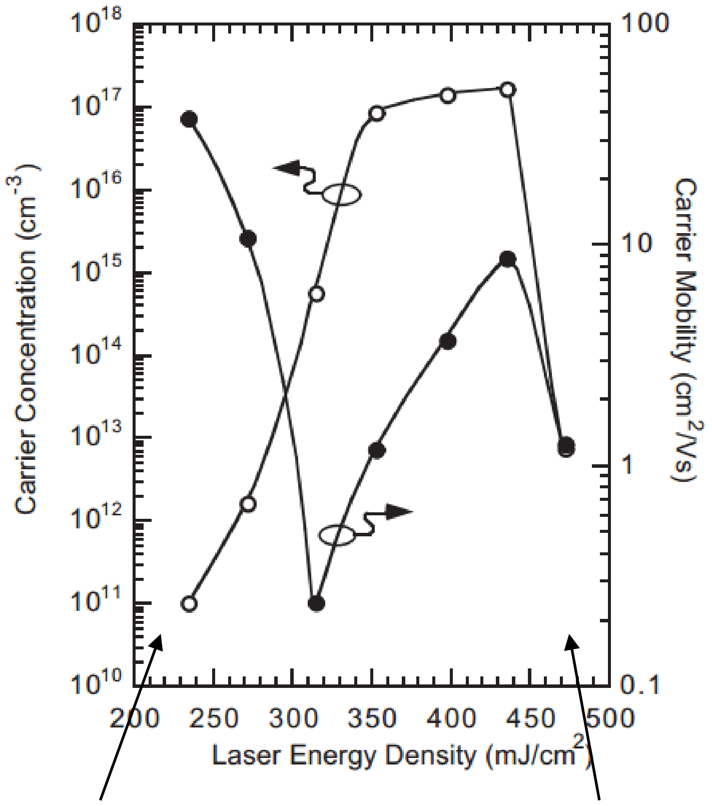
Grain growth model

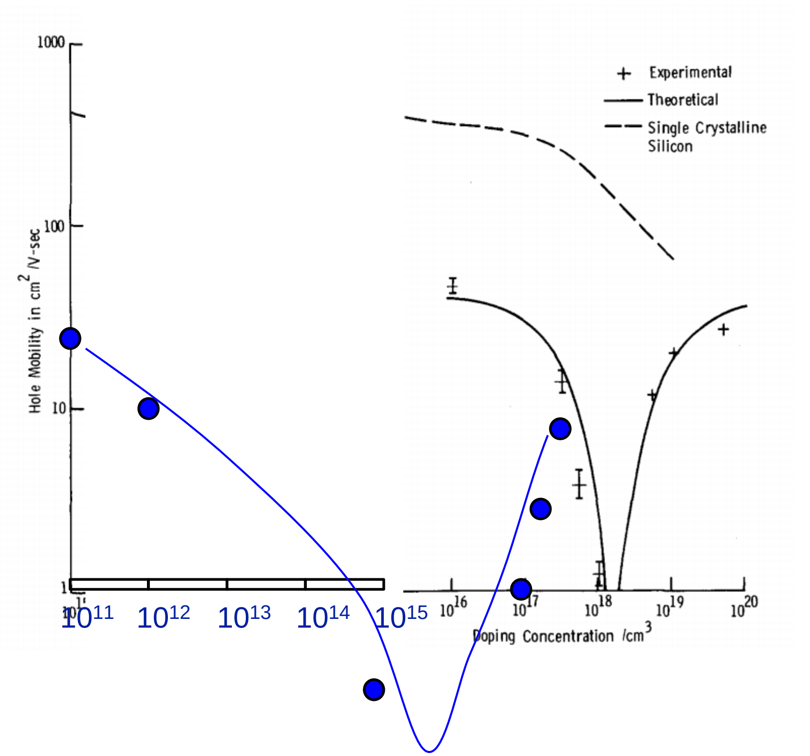


Grain boundary growth
shifts to lower fluence
with lower melting temperature
(here: alloy with Ge)

Jang, materials (2019)

Electrical properties (Hall effect)





crystallization threshold

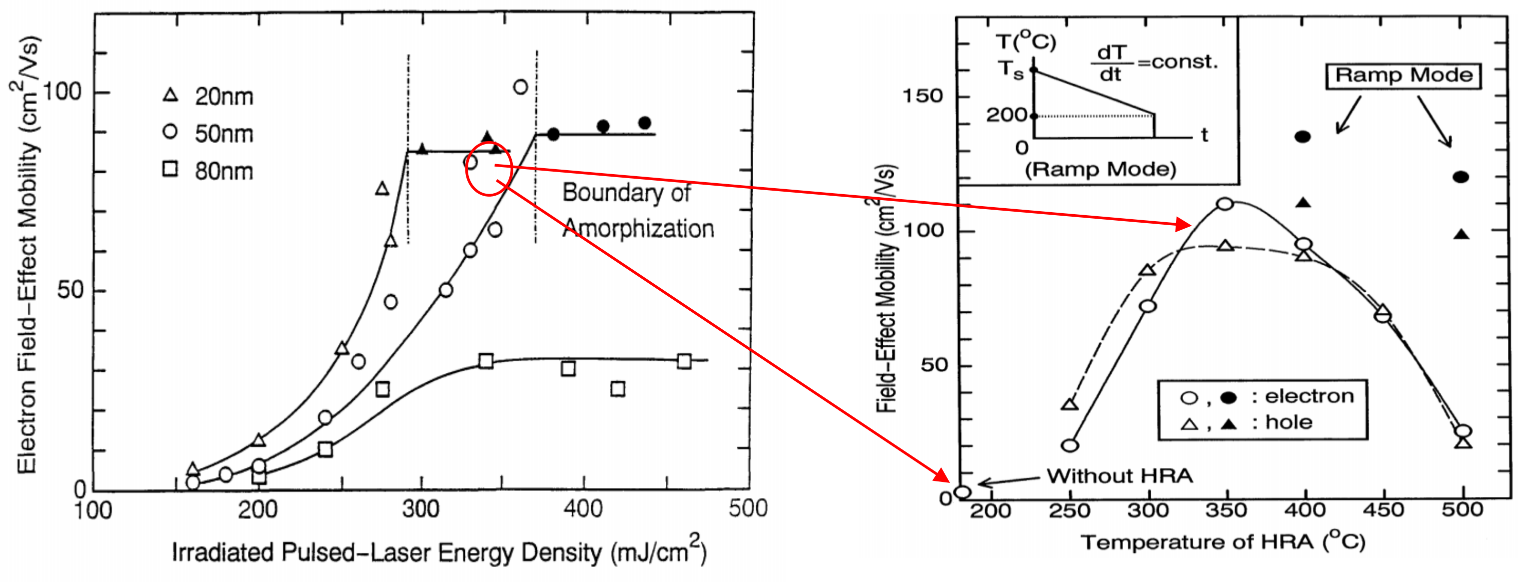
amorphization threshold

authors apply Seto model
=> GB trap density of 5×10^{12} cm^{-2}
(basically every surface atom a trap)

Higashi, JJAP (1999)

PV-lab
IMT NEUCHATEL

Passivation of grain boundary traps



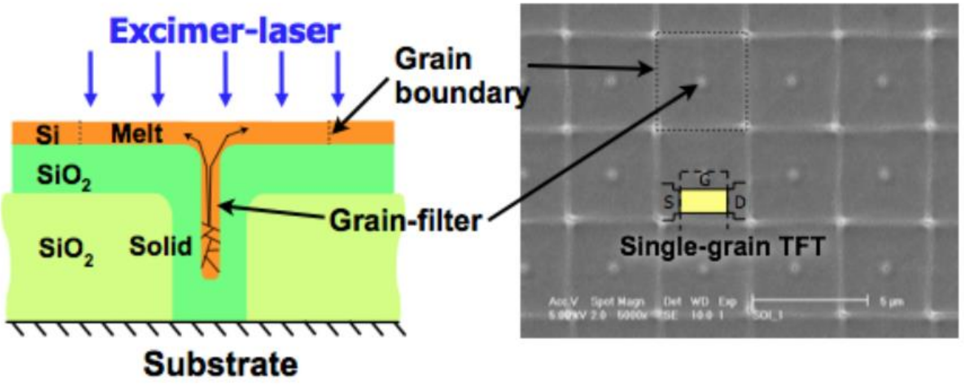
Hydrogenation of GB traps (here by H-radicals)

- optimum around 350°C
- H-loss >400°C revertible by 2nd treatment
- obtain higher mobility for slow cool-down

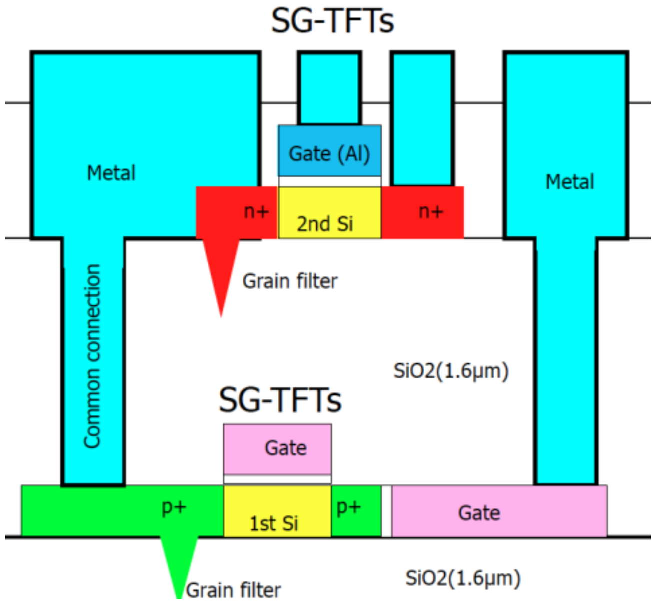
Note: channel mobility, not same as Hall mobility

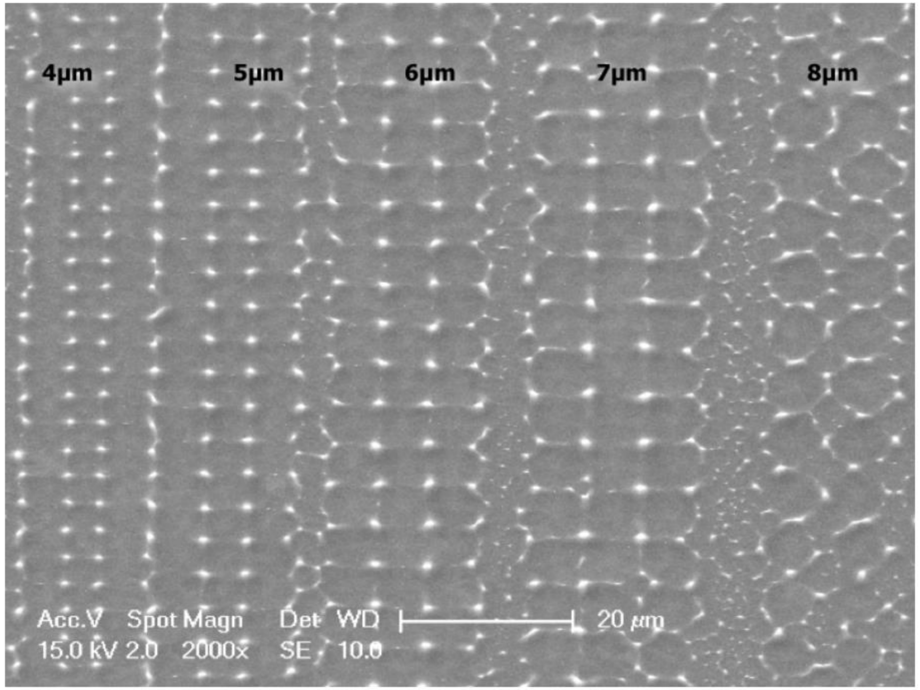
Shimizu, JJAP (1991)

Grain boundary engineering



a) pattern SiO2, deposit a-Si, laser anneal
b) bottom of hole crystallizes first (coldest point)
c) seed for epitaxial growth away from hole
d) form spike at defined position
e) align TFT with initial pattern

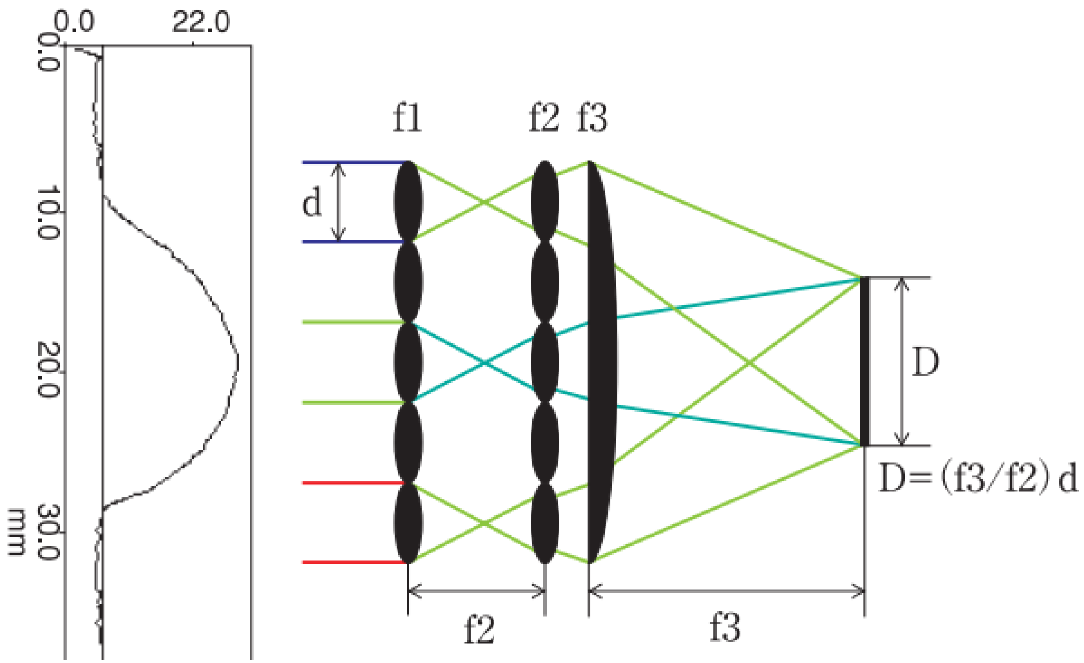


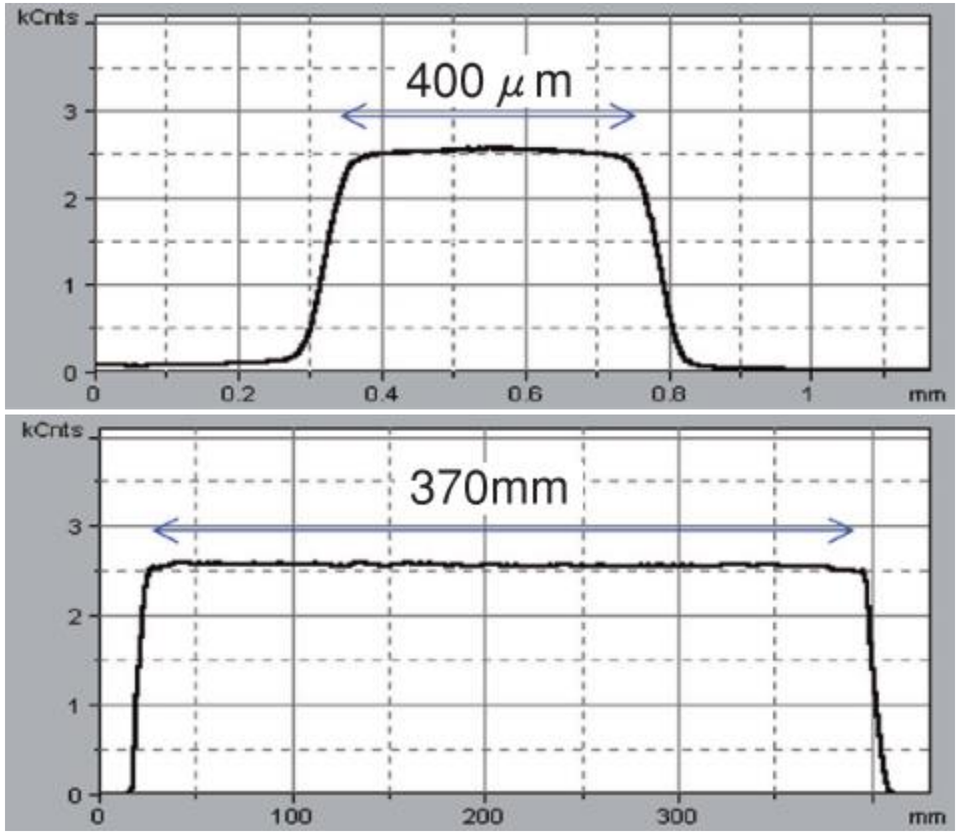


=> epi TFT, even stacked

Ishihara, IEEE TED (2014)

Upscaling: optics for beam shaping





Laser output

e.g. 13 mm x 35 mm

After homogenization: “top-hat”

e.g. 0.4 mm x 370 mm

Up-scaling

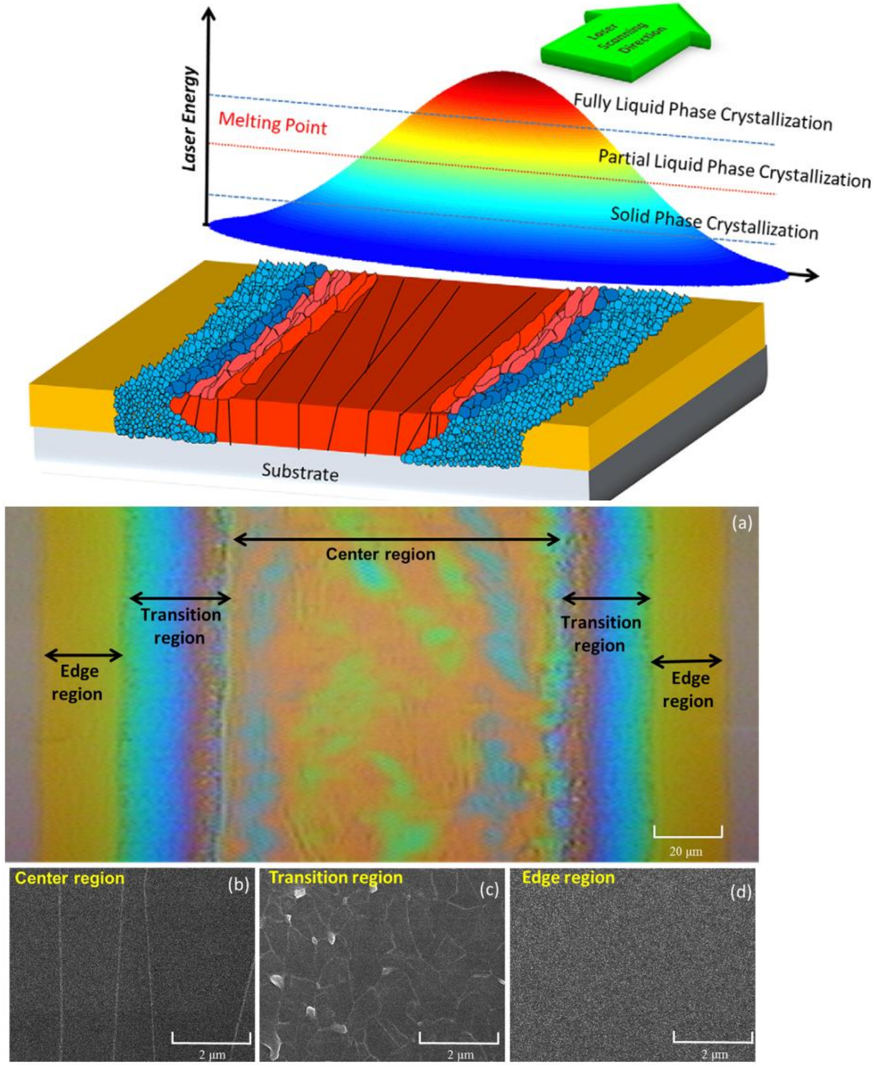
Line shapes of 1300 and 1500 mm demonstrated, enabling Gen6 (1500 x 1800)

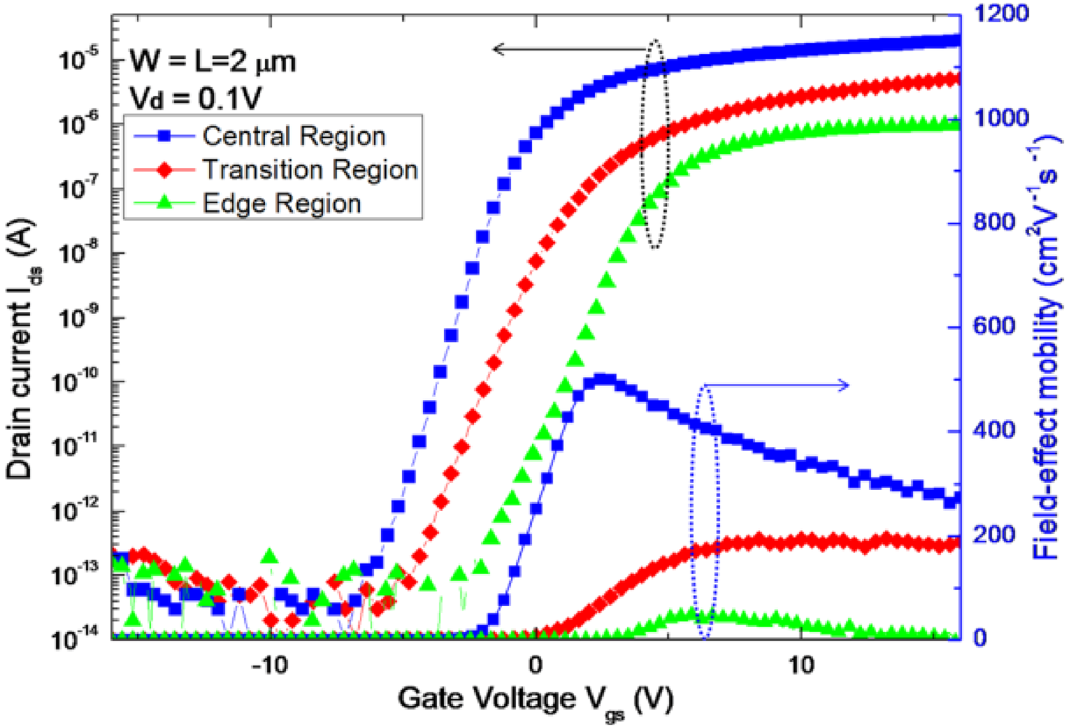
COHERENT Inc.

Solid state laser annealing

Typically Gaussian beam shape

=> needs 2D scanning (here: 532 nm)





TFT: channel parallel to scan direction

- add 100 nm gate oxide (TEOS CVD)
- add 200 nm in-situ doped n-Si (LPCVD)

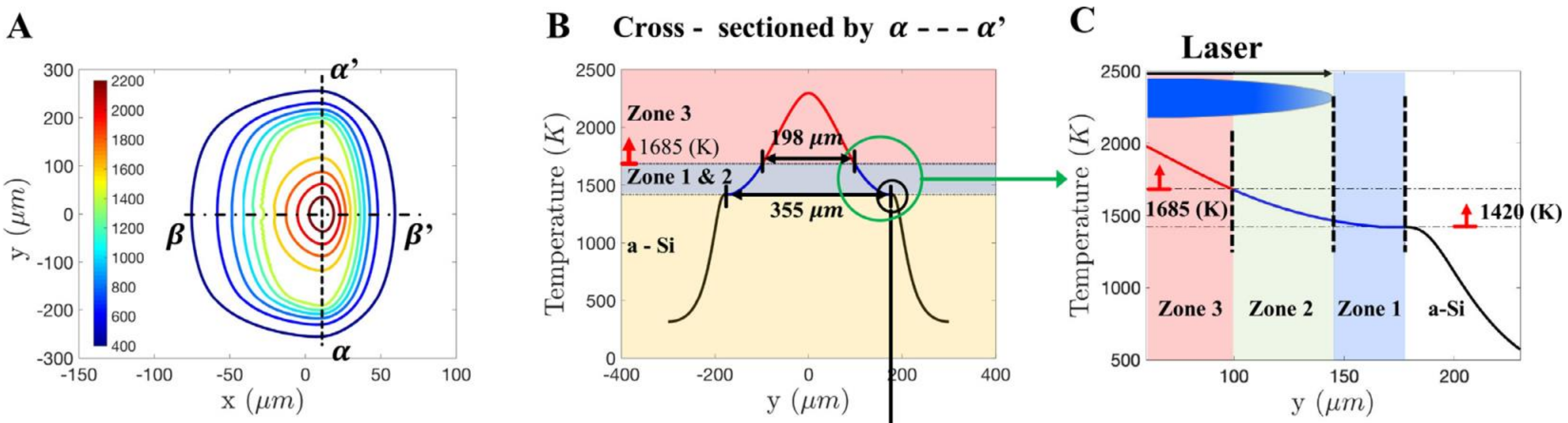
issue: align scans with later channel regions

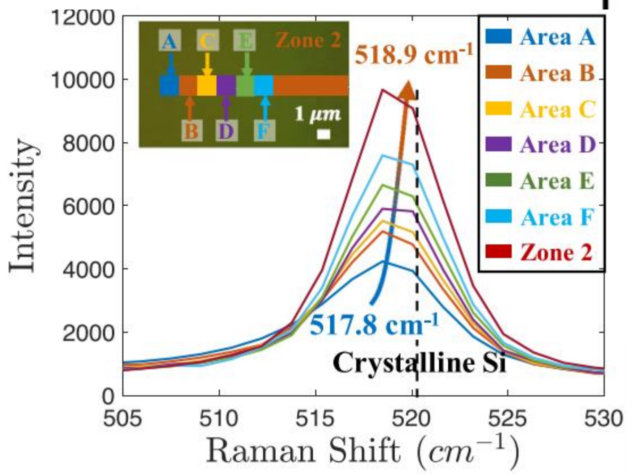
Chou, APL (2013)

F.-J. Haug

Temperature profile

Diode laser (440 nm), elliptical spot (29 µm x 290 µm)





Melting in central region (>2000 K)

Thermal stress in transition region

Relaxed in central region (slower quenching)

Park, TSF (2020)

Summary

- crystalline Si channels key to large mobilty
- Excimer technology upscaled to Gen 6 (1500 mm)
- costly technology
- applied to premium products