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Quantitative copper and iron measurement in silicon using contactless recombination lifetime measurements

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Outline

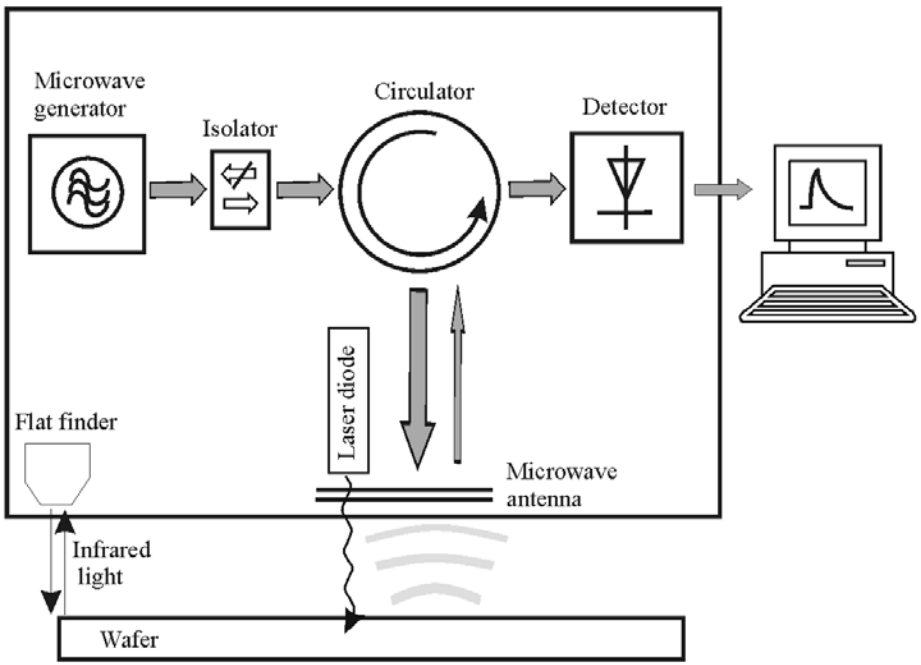
- ✓ Introduction
- ✓ Recombination lifetime methods
  - SPV (Surface Photovoltage)
  - μ–PCD (Microwave Photoconductive Decay)
- ✓ Measuring iron
- ✓ Measuring copper
- ✓ Fe + Cu, how to separate?
- ✓ Conclusions

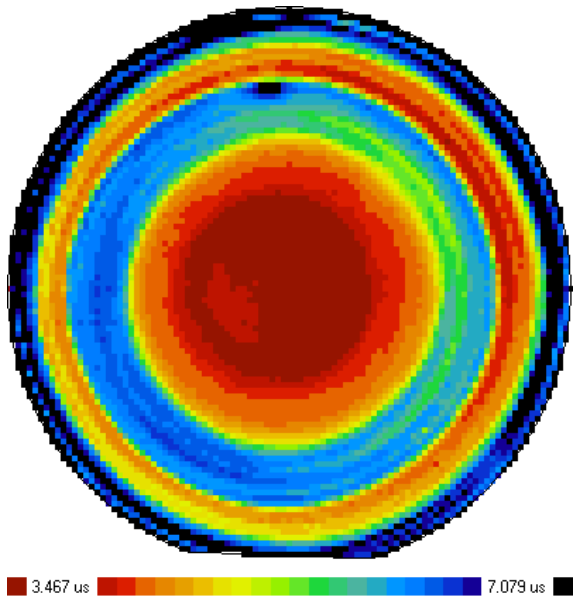
Introduction

- ✓ Iron and copper are harmful impurities in silicon processing
  - carrier lifetime degradation and bulk leakage current in detectors
  - fast contamination of large wafer areas even from point sources and from the wafer backside
  - metals become supersaturated during cooling even at relatively low concentrations, and may form precipitates or complexes
  - …
- ✓ To monitor the cleanliness of silicon processing, it is important to have sensitive and reliable detection tools for metallic contamination
- ✓ Contactless recombination lifetime methods offer an attractive alternative as measurements are fast, non-destructive, and sensitive to measured defect concentrations
- ✓ Problem: How to identify defects from lifetime measurements?

Microwave Photoconductive Decay (μ-PCD)

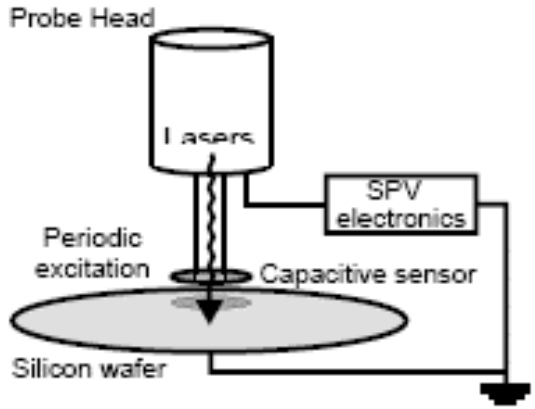
- ✓ Pulsed laser diode creates excess carriers in the wafer
- ✓ Excess carriers contribute to the conductivity of the wafer (photoconductivity)
- ✓ Microwaves are used to detect the change in conductivity
- ✓ A software algorithm evaluates the time constant of the decay from the measured transient
- ✓ Operates at high injection

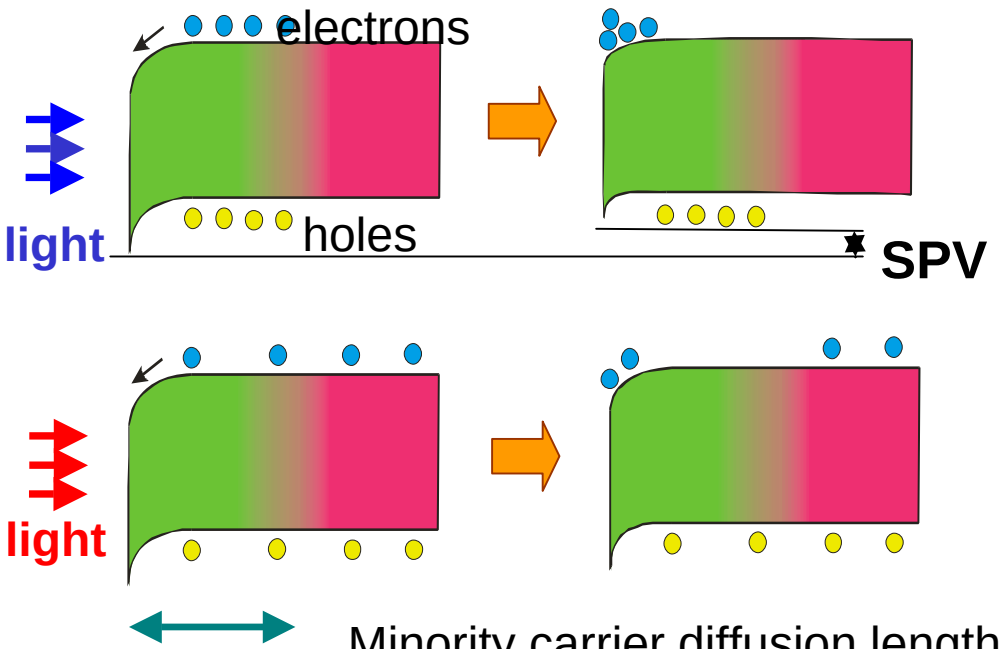


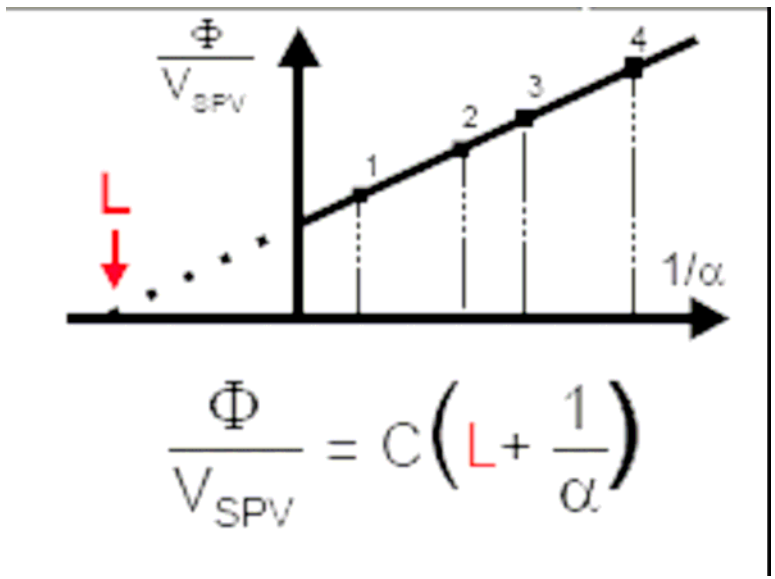


Surface Photovoltage (SPV)

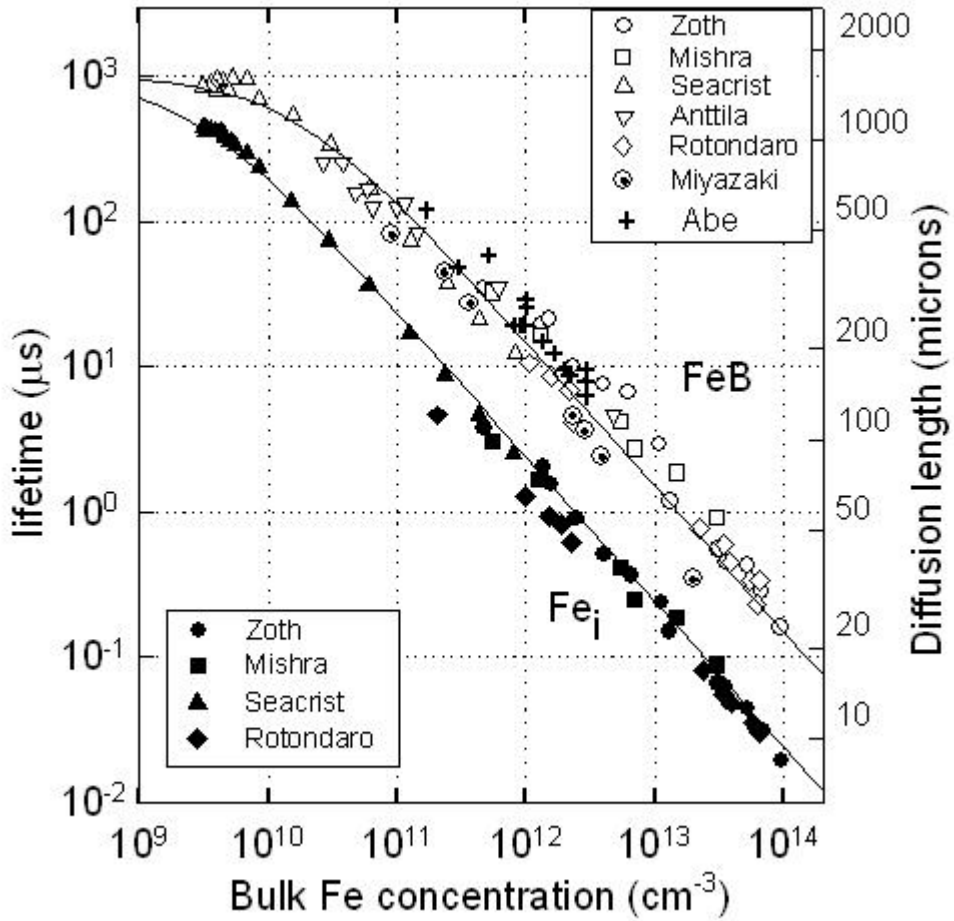
- ✓ *Near-surface band bending attractive for minority carriers*
- ✓ *Variation of light wavelength (different penetration depth)*
- ✓ *Low surface recombination velocity*
- ✓ *Operates at low injection*







Fe concentration monitoring with SPV



$$Fe_i + B \leftrightarrow FeB$$

$\rightarrow$ Room temp. storage

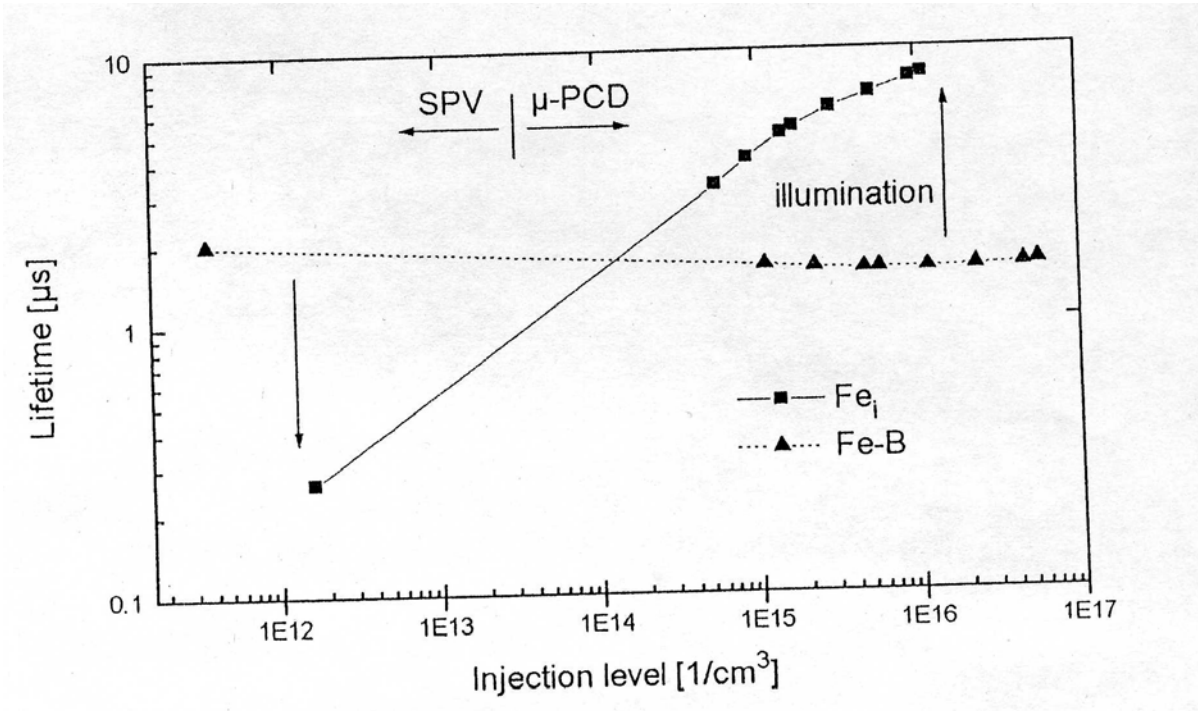
$\leftarrow$ 200^{0}C or bright light

- ✓ Fei has a level at EV+0.38 eV; strong recombination center
- ✓ FeB has a level at EV+0.1 eV; relatively weak recombination center

$$N_{Fe} = 1.06 \times 10^{16} \times (L_{after}^{-2} - L_{before}^{-2})$$

Fe concentration monitoring with μ-PCD

- ✓ Similar to SPV, dissociation of Fe-B pairs
- ✓ Illumination increases the lifetime



$$N_{Fe} = 2.8 \times 10^{12} \times (\tau_{before}^{-1} - \tau_{after}^{-1})$$

Cu monitoring with μ-PCD

1. Problem: Cu out-diffuses to the wafer surfaces

   Solution : Deposit positive corona charge on the wafer surface

2. Problem: Cu does not introduce deep levels or influence the carrier lifetime

   Solution: Cu precipitates decrease the lifetime. Create Cu precipitates by light illumination

3. Problem: How to improve sensitivity?

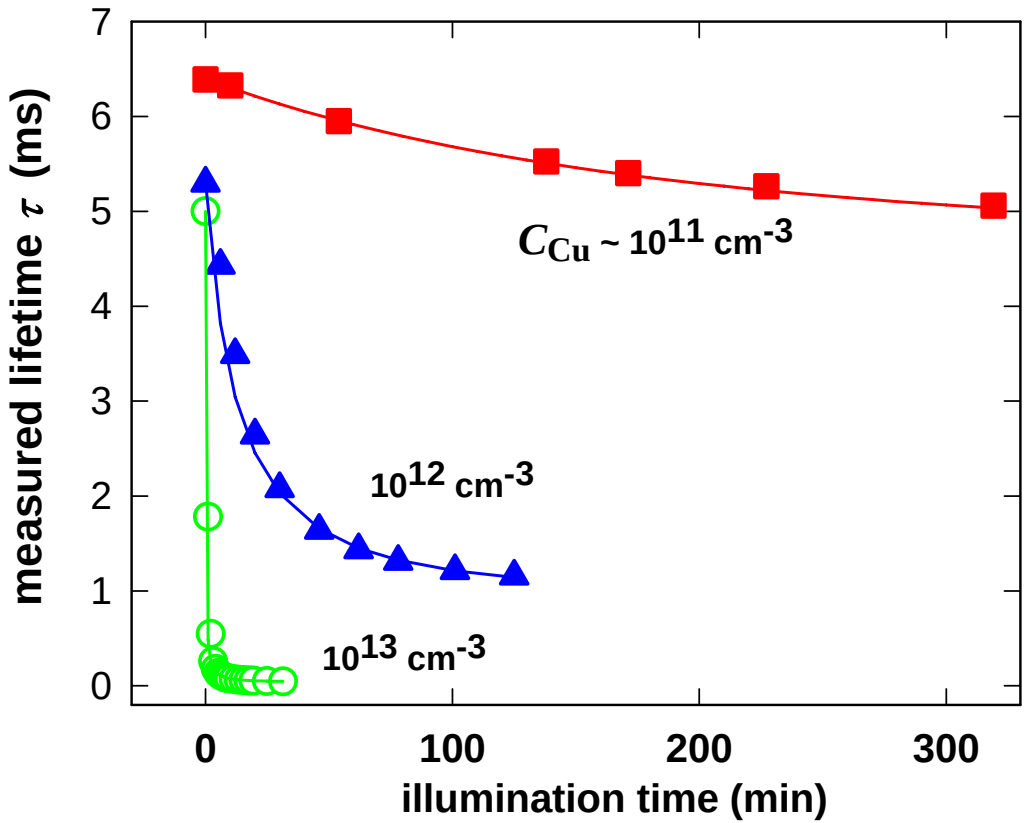
   Solution: Include small oxygen precipitates in the sample

Cu monitoring with μ-PCD

- ✓ Copper contaminated p-Si is illuminated with high-intensity bias-light
- ✓ Distinctive decrease is observed in the recombination lifetime
- ✓ Oxygen precipitates have a significant effect on the light activated recombination lifetime
- ✓ The effect of light activation on the recombination rate is permanent

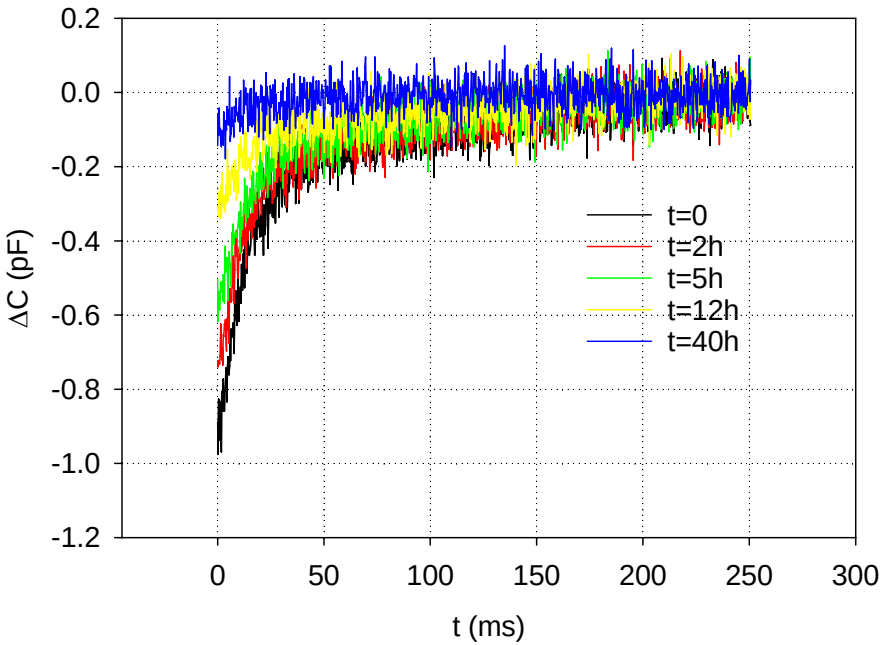
High-intensity light activates the precipitation of interstitial copper

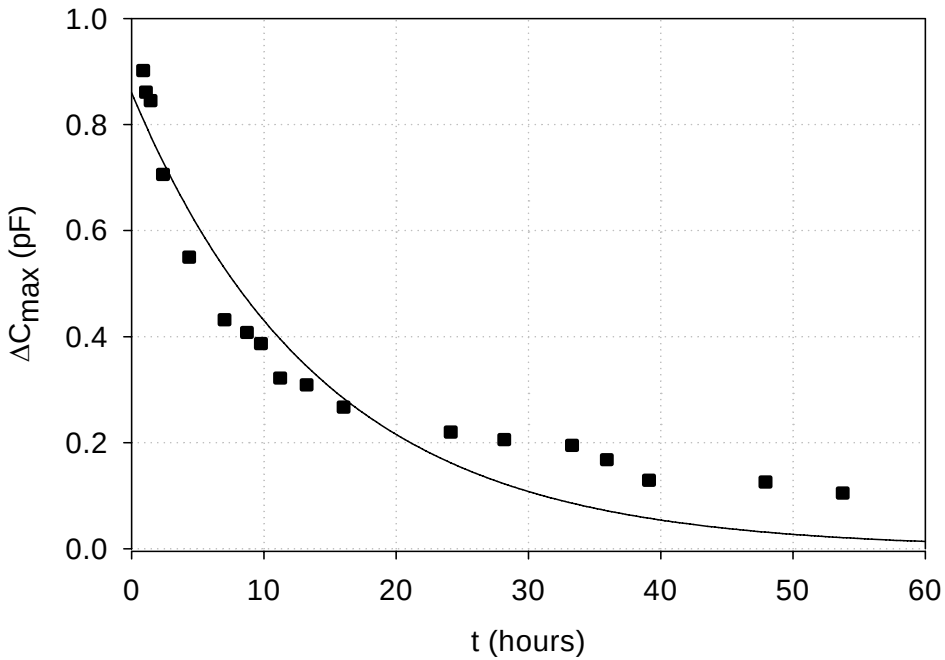
An easily applicable method to detect low copper contamination



Copper studies, TID

- ✓ In order to make this a quantitative method, copper concentration has to be measured by another independent method
- ✓ TID (Transient Ion Drift) induced capacitance change can be used to measure the interstitial copper concentration at RT in *p*-Si

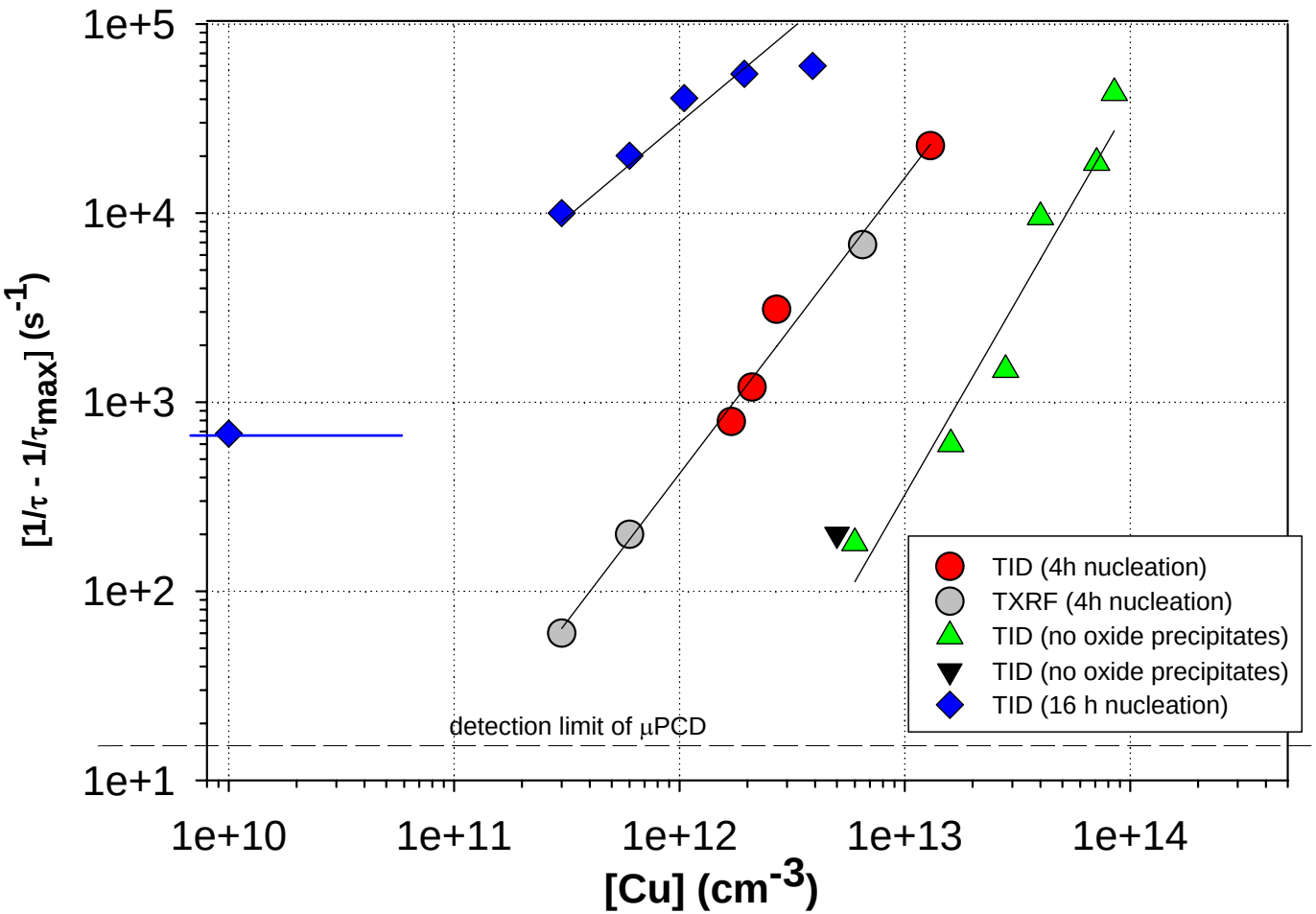




Note: The samples were copper contaminated over a year ago, copper is still in the interstitial form. Corona charge is very effective in preventing out-diffusion!

Quantitative detection of Cu by lifetime methods

- ✓ A systematic dependence of light activated lifetime vs. copper concentration is found
- ✓ Detection limit depends on the density of oxygen precipitates



TID equipment provided by Semilab Inc. Hungary

Conclusions

- ✓ We have developed a new contactless characterization method for Cu in Si, which is based on Cu precipitation under light illumination
- ✓ Under high-intensity illumination copper precipitates in a wafer bulk in p-Si at low concentration level degrading the recombination lifetime considerably
- ✓ Positive corona charge can be used to prevent out-diffusion of copper
- ✓ Oxygen precipitates provide effective heterogeneous nucleation sites for copper under high-intensity illumination

These observations provide an effective non-destructive method to detect copper contamination in p-Si, whose sensitivity is well below 10^{12} cm^{-3}