Range & Defects in Channeled 10 MeV Dopants in Si(100)

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1. A bit about **stopping powers**
2. Implant tool for channeled ions (S-UHE)
3. Implants and **Range** data
4. A bit about **photoluminescence**
5. Comparison of **PL recombination intensity** for
channeled and “**random**” beam incidence.
6. Other recombination-sensitive probes: **PMR** (“TW”)
6. PL recombination center **“intermittencies”**
7. Summary

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Abstract

Low-dose **7.5 MeV B^+** and **10 MeV P^+ and As^+** profiles in Si(100) with "**random**" (7/23 tilt/twist angles) and **highly-channeled** (0/0) ion beam-crystal orientations were studied with **SIMS**, the MC-code, **IMSIL**, and by photoluminescence (**PL**) and a variety of other carrier recombination sensitive defect metrologies (**JPV, PMR**).

Time signatures of curious "**intermittencies**" in the PL signals are also discussed.

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A bit about Stopping Powers

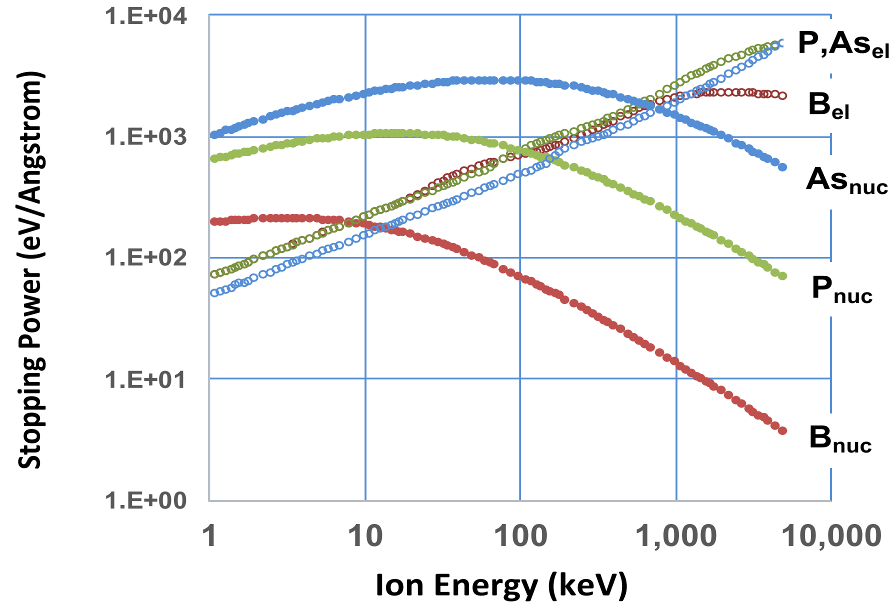
Stopping powers of ions (eV/Å) in matter are a sum of 2 types of collisions:

$$S(eV/Å) = S_{el} + S_{nuc}$$

Electronic stopping: S_{el}
(collisions of ions with loosely bound electrons)
Nuclear stopping: S_{nuc}
(collisions of ions with core electrons & nuclei)

Highly-channeled ion profiles are characterized by **lower S_{nuc} values** and **deeper profiles.**

Lower S_{nuc} values *should* create **less damage** (strong atom displacement collisions).



Electronic (S_{el}) and nuclear (S_{nuc}) stopping powers (eV/Angstrom) in Si for B, P and As from 1keV to 10 MeV.

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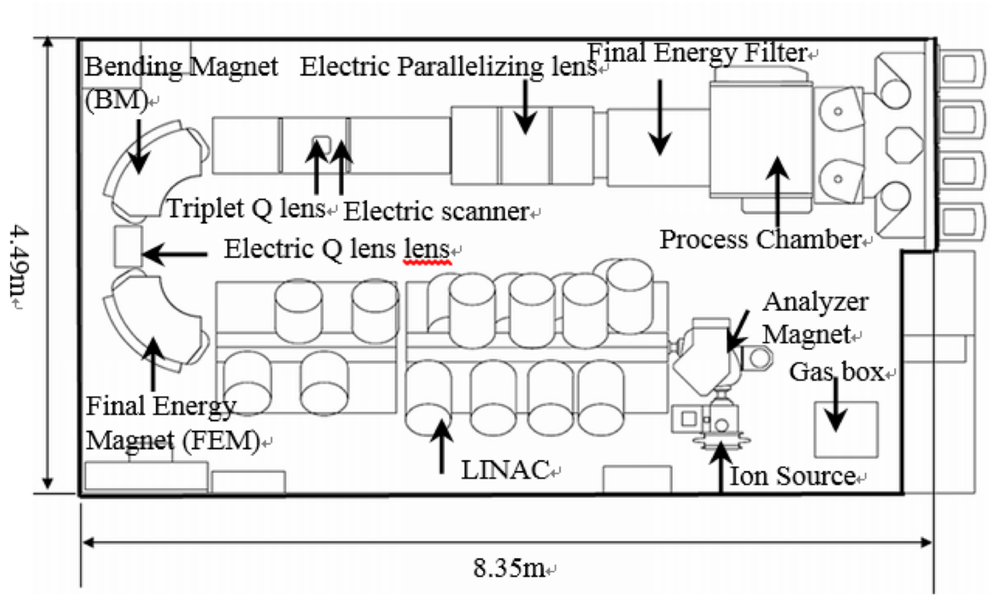
Implant tool: SMIT S-UHE (Ultra-high Energy)



LINAC acceleration with 18 RF (13.46 Mz, 80 kV), sequential quadrupole focus elements, electrode phase & amplitude control for ion velocity filtering.

Magnetic ion energy filter, electrostatic scanner, parallelizing. Deflection energy filter before wafer.

Folded beamline: long-path beam alignment control.

Ion energy range: 6.8 MeV (As, P), 5MeV (B).

Single charge ions:
2 – 780 puA.

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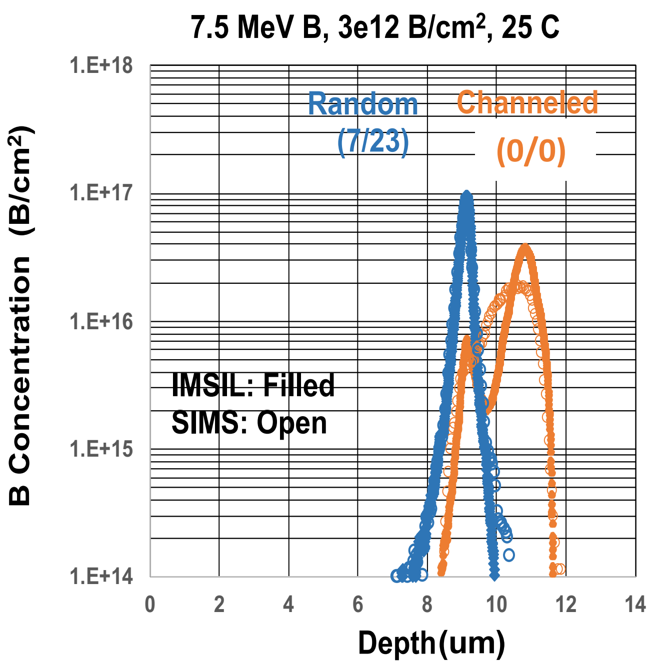
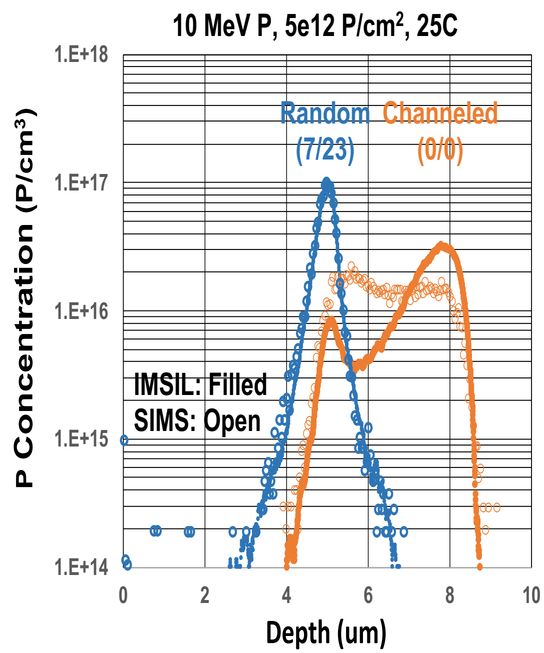
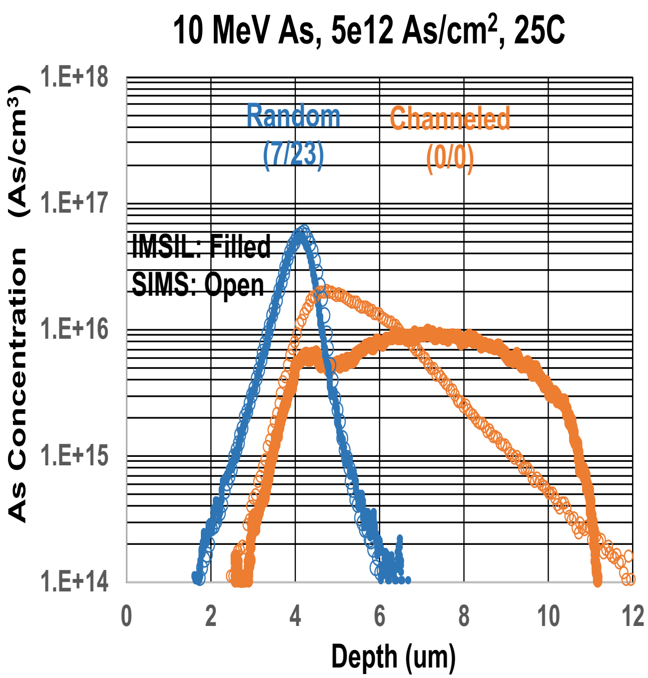
Implants & Range

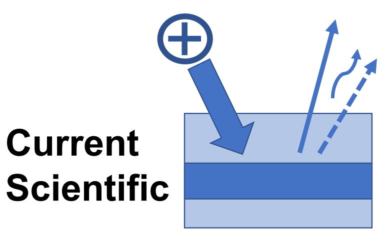
IMSIL: A MC code for **IM**plants in **SIL**icon (100): Prof. Gerhard Hobler, TUWein







SIMS and IMSIL profiles for channeled (0/0) & random (7/23) incidence
7.5 MeV B and 10 MeV P and As implants at 25°C.



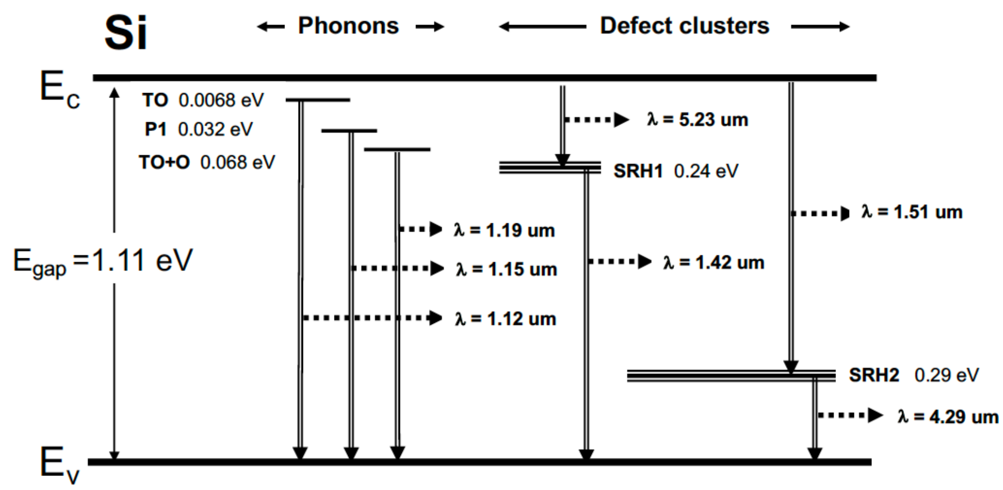
A bit about photoluminescence (PL)

Luminescence Timeline:

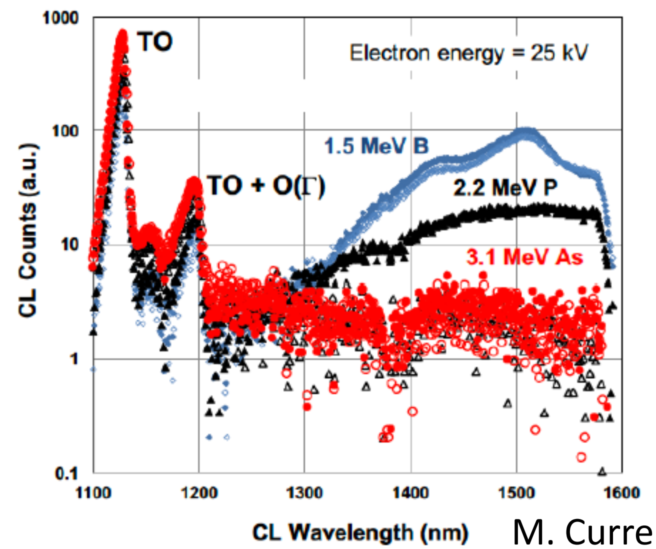
1. Electrons excited into conduction band by energy (electron or photon) >1.1 eV.
2. Electrons rapidly loses energy to conduction band edge (by phonon emission).
3. Si band alignment requires coupling with phonons or mid-gap carrier recombination centers (damage) for electrons to return to valance band.

All transitions can emit **phonons** (heat) or **photons** (PL and CL signal).

Radiative (light) transitions are a **small** fraction of total transitions: **1 : 1e-7**.



Cathodo (electron driven) luminesce



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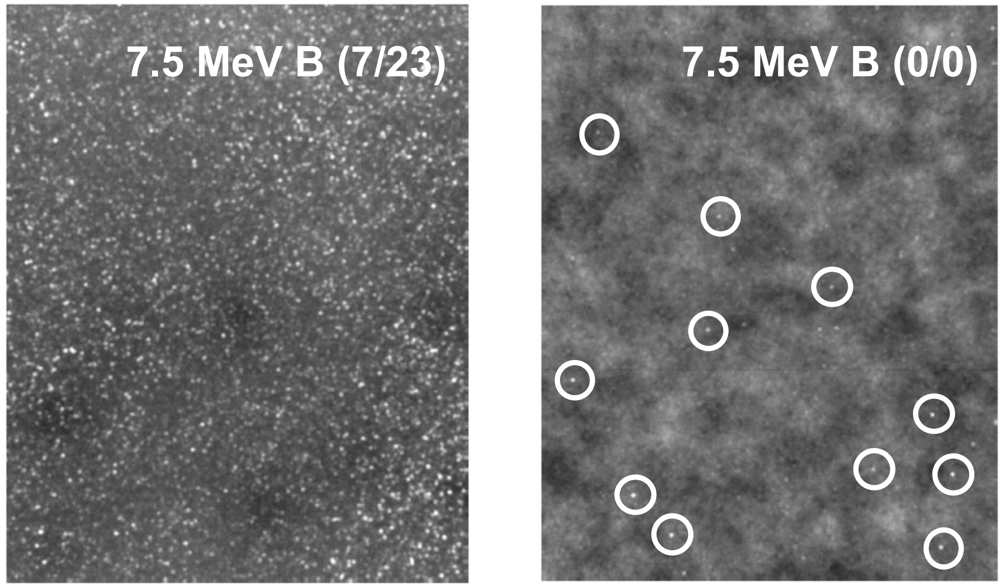
Photoluminescence Signals: Annealed B



PL images, showing defect-assisted recombination light for wavelengths >1300 nm, for random and channeled 7.5 MeV B implants at a dose of 3e12 B/cm^2 (right) and annealing at 950^o C for 3 minutes.

Note the dense radiative recombination centers in the random PL data for 7.5 MeV B compared to the relatively sparse radiative recombination centers (in circles) for the channeled orientation implant.

The image field of view is 175 x 140 um.

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Radiative recombination at damage centers.

Generally λ > 1300 um. (photon <1.1 eV)

Number density of recombination events:

N_{eh} (recombination) = S_{in} ($h\nu$>Eg) * (Absorption fraction) * [P_{eh} = [$N^{non\text{-}rad}$ + N^{rad}]]
where:
S_{in} ($h\nu > E_{gap}$) = excitation *input) signal power density with ($h\nu > E_{gap}$)
Absorption fraction = power incident - power reflected
P_{eh} = probability of e-h generation per absorbed hv =100% (?)

Normalized Defect Band PL Signal

$$\boxed{[\, S^{PL}_{SRH} / S^{PL}_{BB}] = [NDPL] \approx n_{SRH}}$$

(*Otherwise,* $n_{SRH} = \sum$ [cluster brightness$_j$ *cluster size$_j$ * # clusters(j)]
with apologies to M. Planck, A. Einstein, etc.

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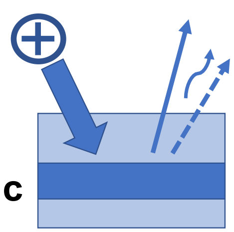

Defect Band PL: annealed samples

Defect band PL, at wavelengths >1300 um, show strong effects of channeling (lower defect levels), especially for the high S_{nuc} ions, As and P.

B implanted samples have low defect signals (low S_{nuc}), with channeling effects in the noise.

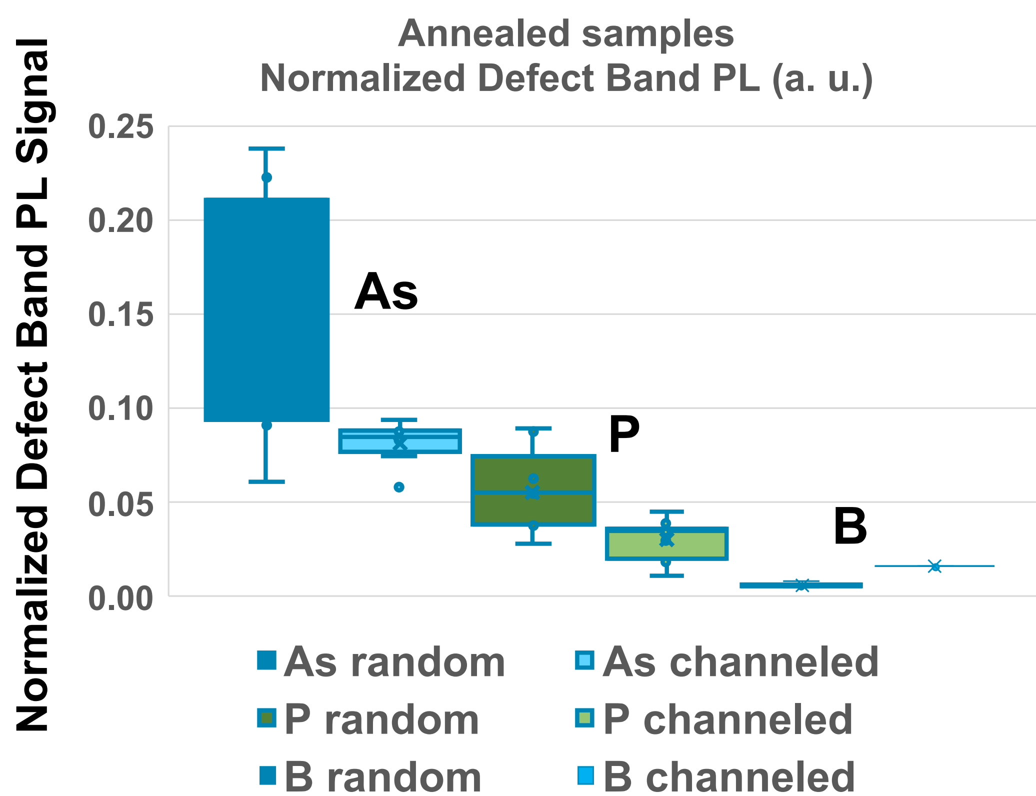

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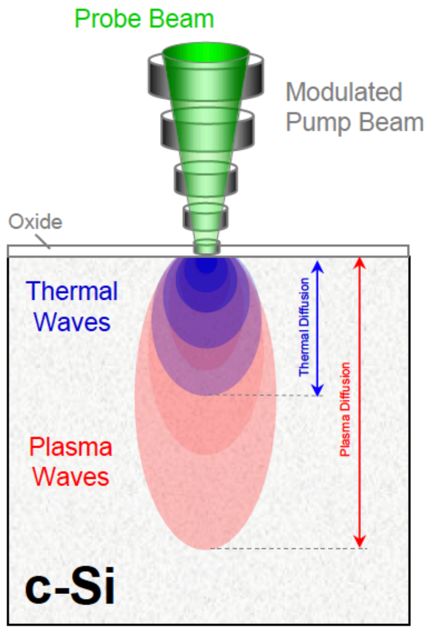
Photo-modulated Reflectance: PMR



Reflectance measured with 2nd, DC laser beam.

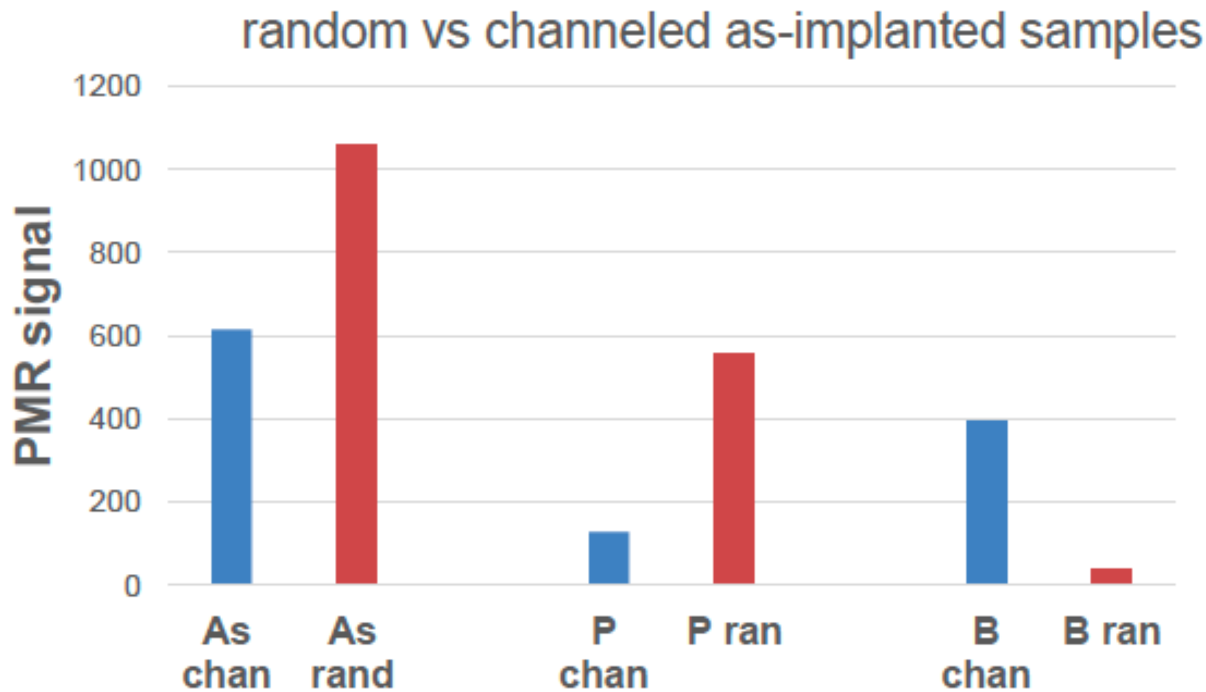


Photo-modulated reflectance (PMR) signals are strongly sensitive to shallow damage (As & P) and less sensitive to deeper B damage. Clear channeling effects on carrier recombination at defects are seen for As and P implants.

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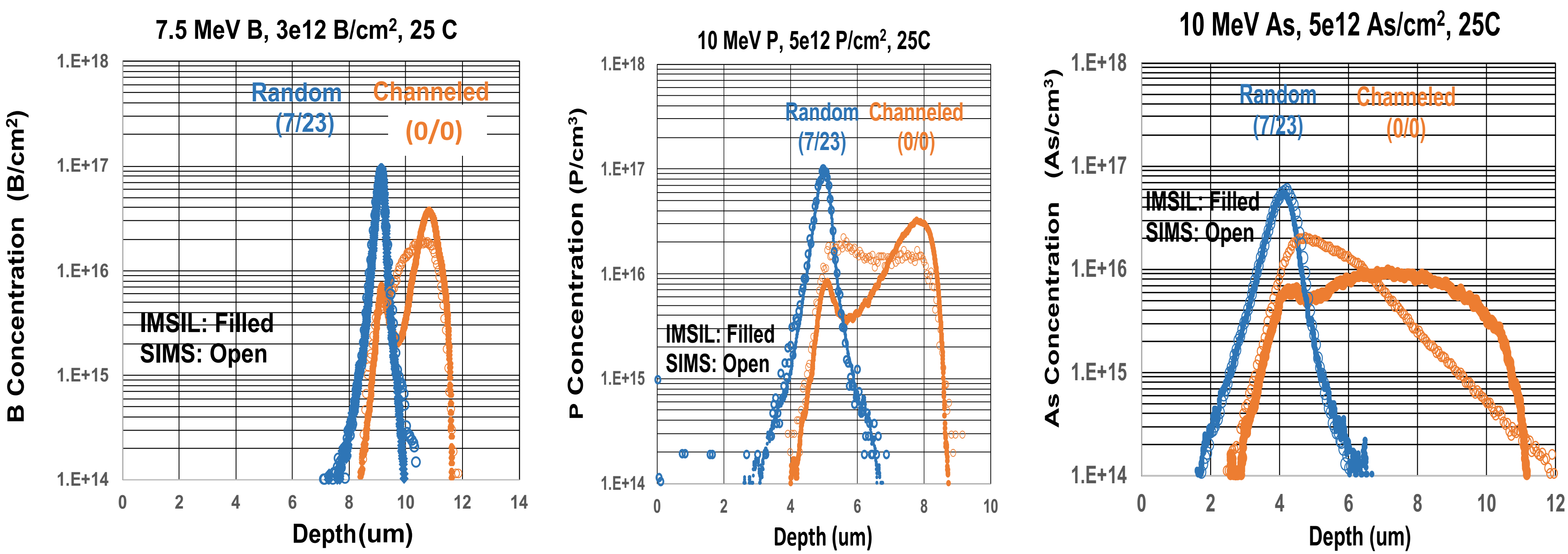

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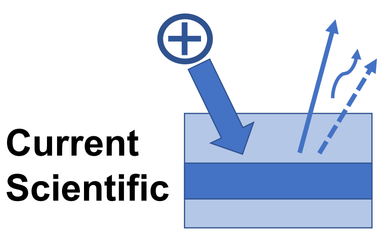
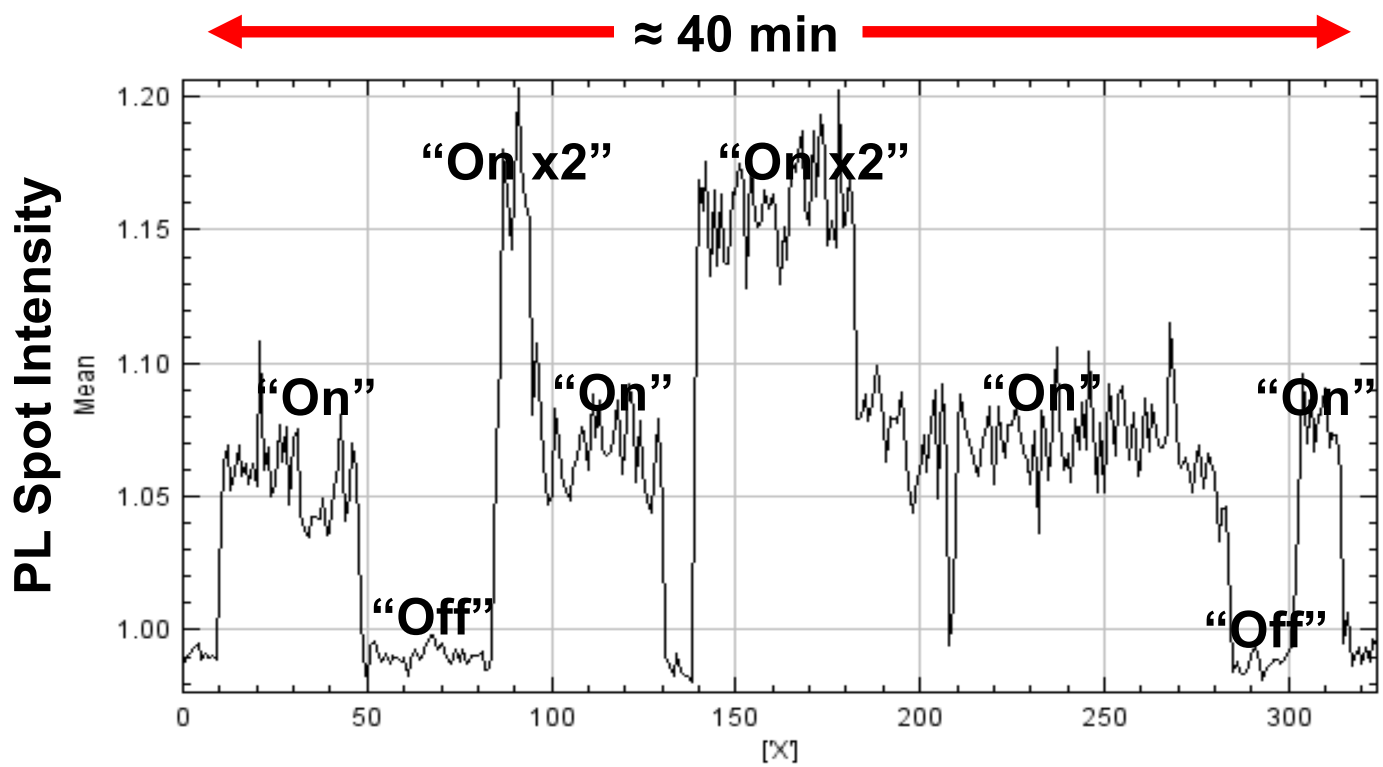


PL "Blinking" during Recombination



Individual PL defect signals over a time sample of ≈40 min, showing 3 levels of luminosity, indicating a change of state at a defect site as carriers are recombined. A PL "intermittency".

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Jahn-Teller* Distortion (1937).

"**any non-linear molecular system** in a **degenerate electronic state** will be **unstable** and will undergo **distortion** to form a system of **lower symmetry** and **lower energy**, thereby removing the degeneracy."

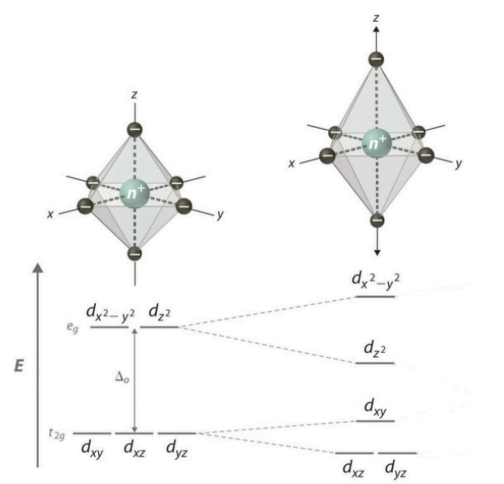
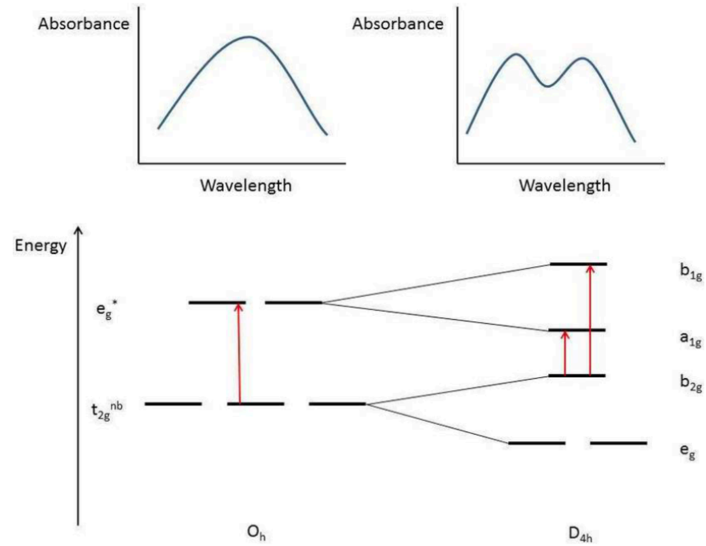


Figure 2: Illustration of tetragonal distortion (elongation) for an octahedral complex.



Postulate: Vibrations and structure of defect (including metal precipitates) sites may change with phonon emission during carrier recombination. A topic worthy of study and PL intermittencies may be possible defect spectroscopy.

Edward Teller* (1908-2003): Hydrogen bombs, Star Wars, etc.

Summary

1. **Carrier (electrons & holes) recombination** occurs by:
   (1) phonon-assisted (temperature dependent) **band-to-band** transition or
   (2) **coupling with damage/defect sites** (in mid-gap regions). More phonons.

2. **Carrier recombination** results **in measurable eff**ects:
   (1) charge loss:[**Junction photovoltage(JPV)**:R_{sheet}, Junction leakage current]
   (2) phonon emission (heating):[**Photo-modulated Reflection (PMR)**,aka “TW”]
   (3) photon emission (IR light): [**Photo**/Cathodo-**Luminescense** (**PL**/CL)].

3. **Photoluminescence (PL)** provides **quantifiable measures** of defect densities **throughout the full volume** of a doped junction & depletion layer.
   (1) **Radiative center density** (at low damage density levels)
   (2) **Mid-gap transition intensity** (at high & low damage levels)

4. **Work to be done:** (1) calibration of PL intensity levels with IC leakage,
   (2) correlation with other recombination-sensitive measures (PMR, JPV, etc.),
   (3) understanding of PL intensity fluctuation & defect center structure.

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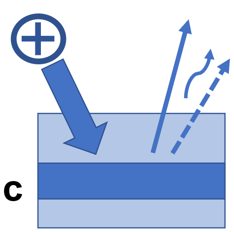

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Good Fortune in 2023, the Year of the Rabbit.

Nengajo for 2023, Year of the Rabbit
with sketch of Rakoto Honen-in south gate.

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