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Defects and Gain Degradation in pnp Si BJTs Irradiated with Different Mass Particles

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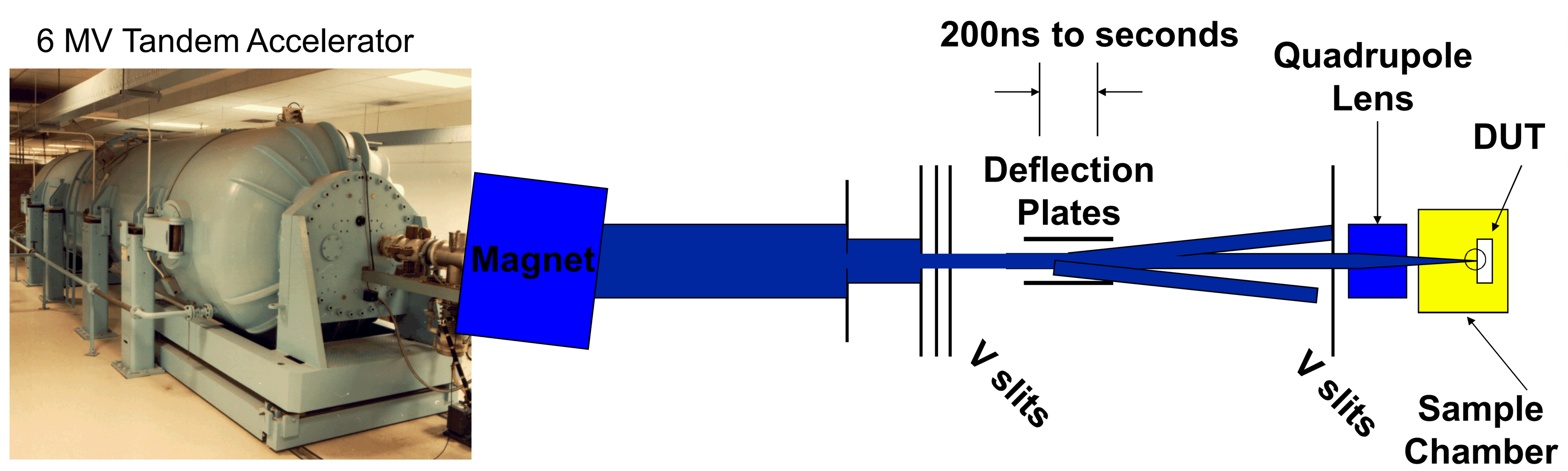
Abstract

We use deep level transient spectroscopy (DLTS) to explore the defects created at the base-emitter junction of pnp Si BJTs by different mass particles. We found that V2* and E5 defects dominate the gain degradation whereas VP only has a small contribution.

Ion Beam Laboratory (IBL)

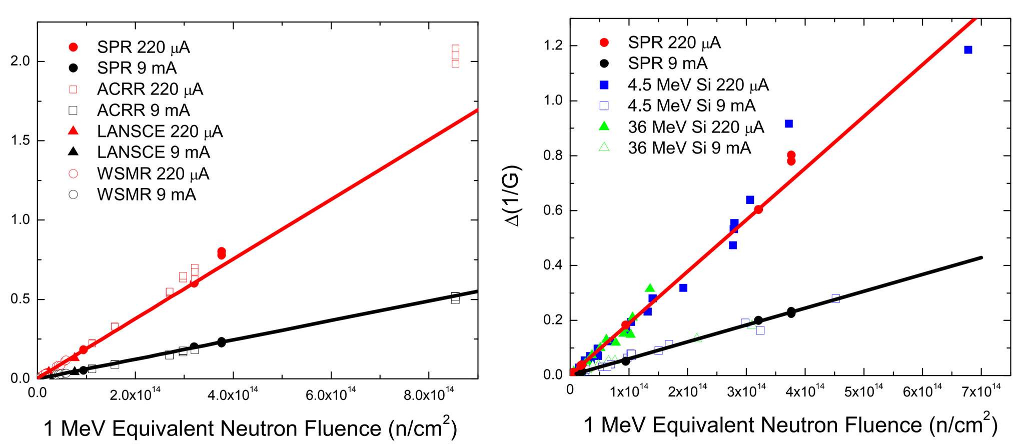


Specifications of the Sandia National Laboratories Tandem

- Ions: H to Au
- Energies: (q+1)*Terminal Voltage
- Focused beam (mm – μm)

Ion-to-Neutron Fluence Conversion

Active gain



The damage constant is the same for all the tested neutron facilities.

Provides a method to relate ion-to-neutron damage through late-time gain degradation.

Displacement damage follows Messenger-Spratt equation:

Damage Constant

$$\frac{1}{G_\infty} - \frac{1}{G_0} = k\,\Phi \;\alpha\; \#\,of\,defects$$

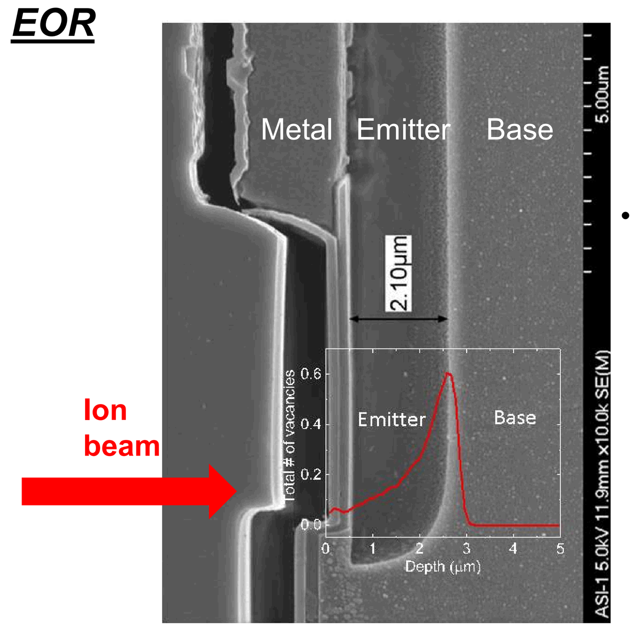
Scale ion fluence to 1 MeV Neutron Equivalent fluence using:

$$\Phi_{neutron} = \frac{k_{ion}}{k_{neutron}} \cdot \Phi_{ion}$$

→ We matched late time gain degradation to translate ion-to-neutron fluence

End-Of-Range (EOR) Irradiations

EOR



- EOR conditions for different ion species:

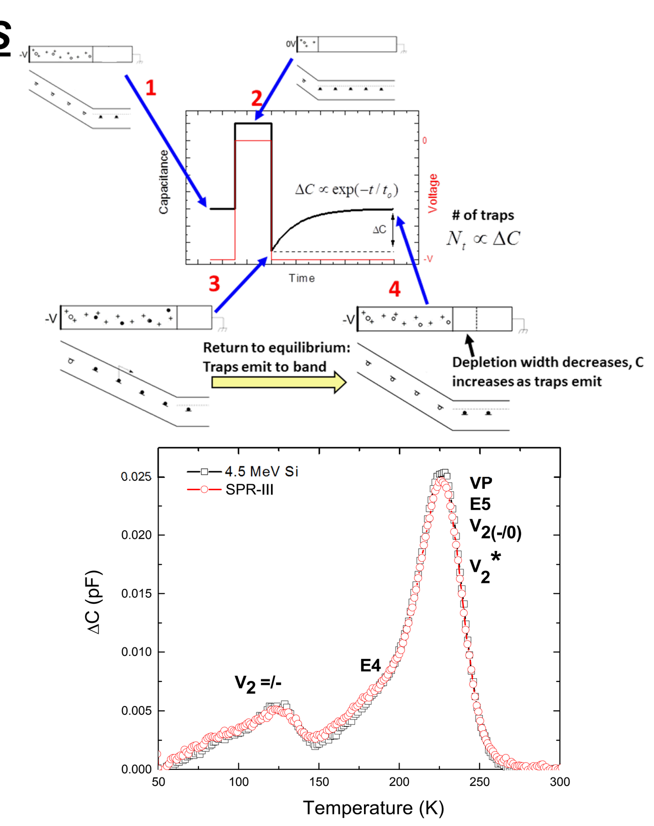
He: 850 keV

O: 3.75 MeV

Si: 4.25 MeV

Au: 11 MeV

DLTS



We adjusted the incident ion beam energy for He, O, Si and Au ions to produce the maximum number of defects at the base-emitter (BE) junction

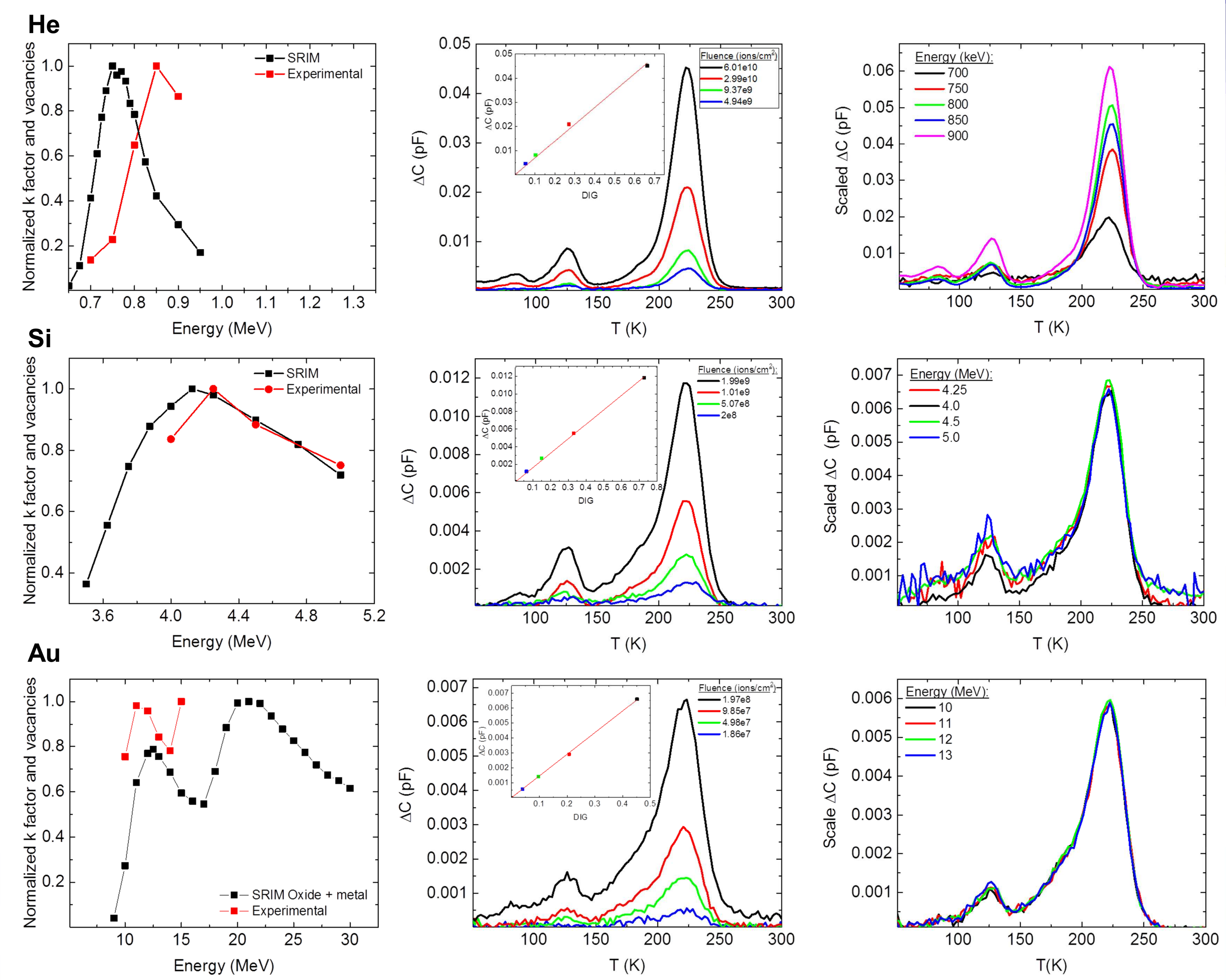
- We have used ion beams to match the amount and kind of defects that neutrons produce in:
  - Si BJTs irradiated with a silicon ion beam

→ We matched amount and type of electrically active defects produced by neutrons using ion beams at EOR conditions

What is the effect of ion species at EOR?

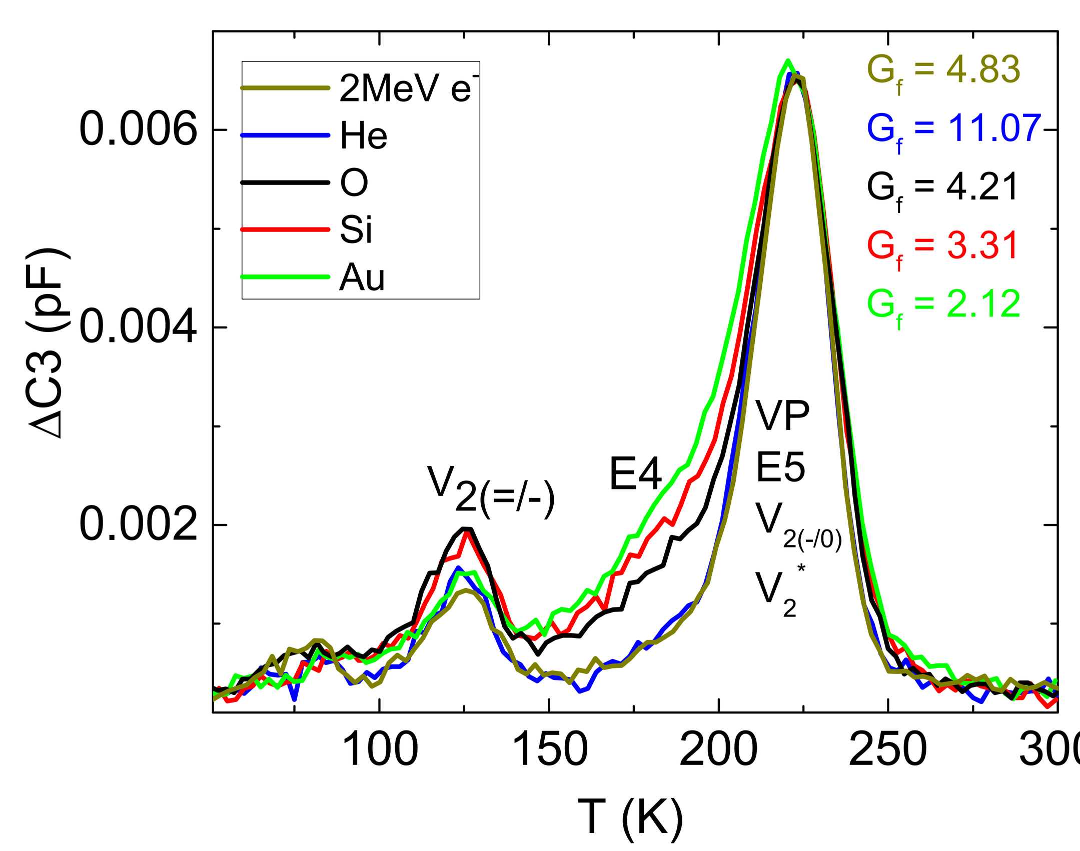
- We performed EOR irradiations with He, O, Si and Au ion beams
  - We found good agreement between SRIM simulations and experimental energy scans (locating BE)
- Maximum DLTS peak height occurs at EOR conditions
- DLTS peak height linearly proportional to fluence

SRIM vs Experimental — *DLTS fluence dependence* — *DLTS energy dependence*



→ We determined EOR conditions and showed DLTS linearity with DIG

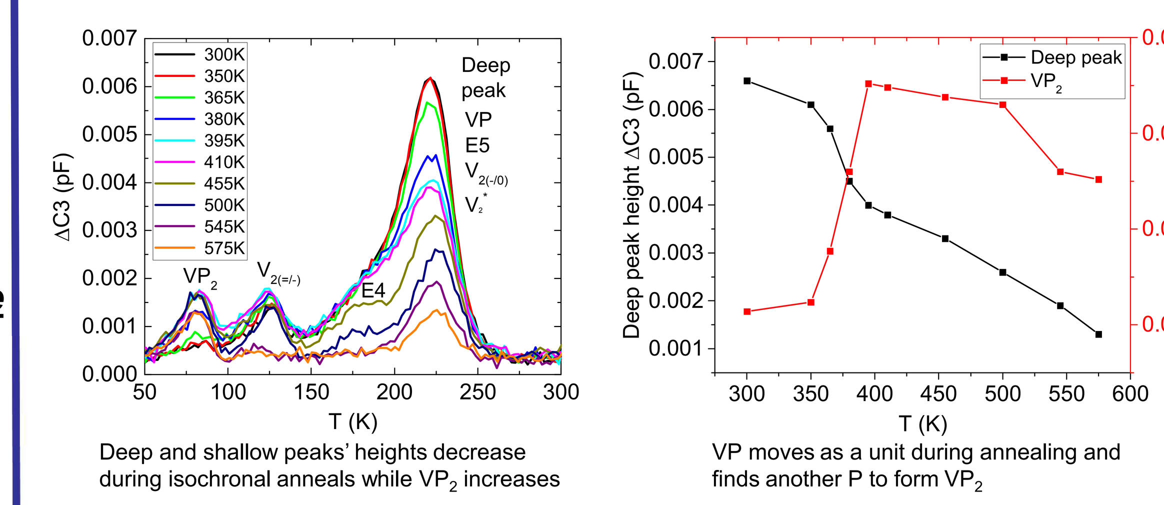
Match defect conditions with EOR irradiations



- We matched defect conditions in pnp Si BJTs with e⁻, He, O, Si and Au irradiations
- Each irradiation produced different gain degradation for matched defect conditions
- Higher gain degradation produced by heavier particles
- e⁻ irradiations produced ionization and displacement damage
- Clustered defects E4/E5 varies with ion mass

→ Different gain degradation produced by different mass particles for matched DLTS deep peak height

Isochronal annealing study on matched vacancy conditions



Deep and shallow peaks' heights decrease during isochronal anneals while VP_2 increases

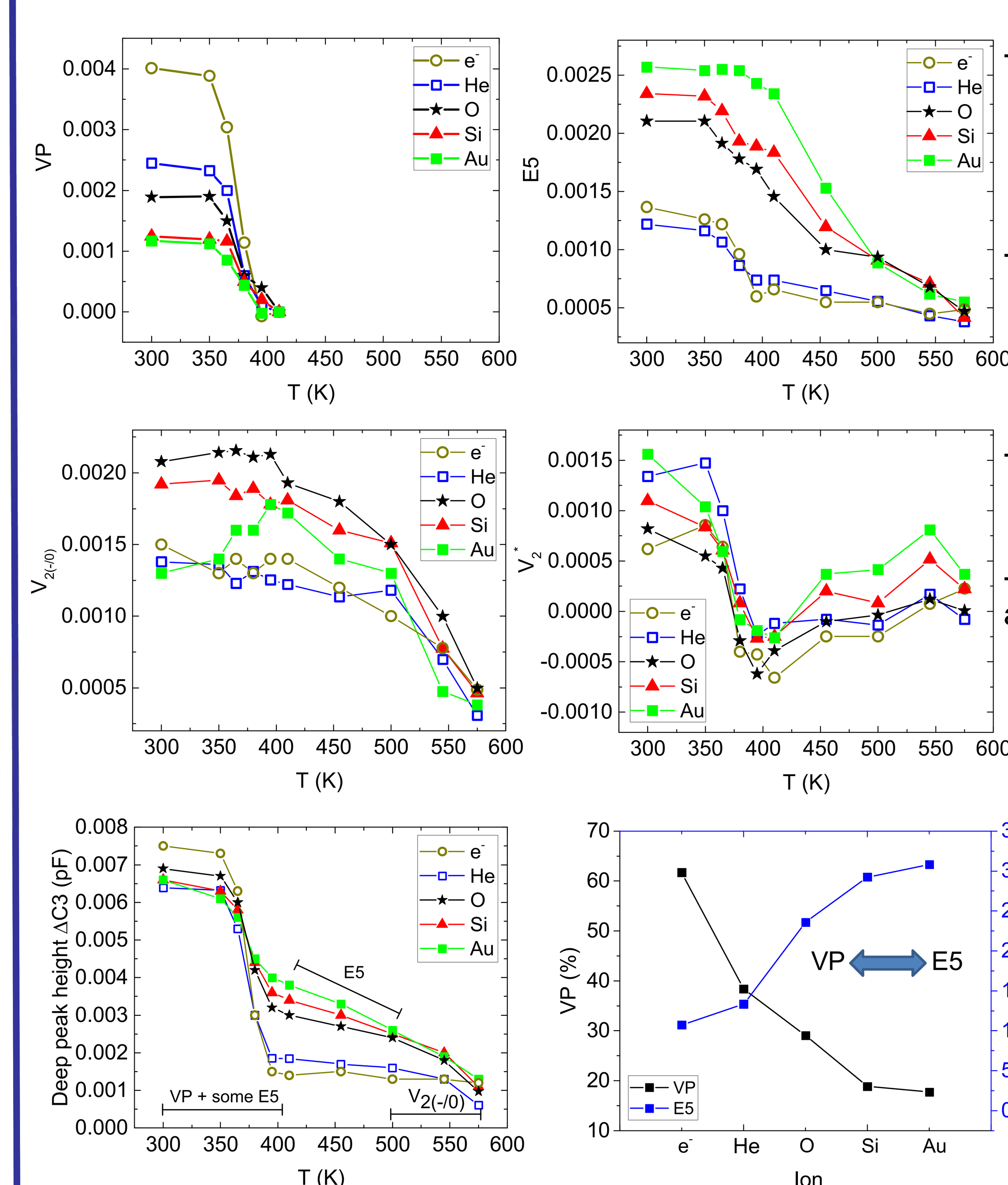
VP moves as a unit during annealing and finds another P to form VP_2

Deep peak = VP + E5 + $V_{2(-/0)}$ + V_2^*

- VP from VP_2
- E5 from E4
- $V_{2(-/0)}$ from $V_{2(=/-)}$,
- V_2^* unknown

→ We did isochronal anneals to find the defect contributions in the DLTS deep peak

DLTS deep peak defect components vs temperature



- More VP defects are created by light mass particles than by heavy particles
- Heavy particles produce more defect cluster-related defects (E5) than Si and He irradiations
- $V_{2(-/0)}$ is known from $V_{2(=/-)}$
- V_2^* is calculated from the deep and its other defect components

	Percentages of defects in deep peak				
Defect	e-	He	O	Si	Au
VP	61.71	38.37	29.06	18.85	17.73 ↓
E5	10.72	13.34	23.58	29.23	30.80 ↑
$V_{2(-/0)}$	15.26	15.54	15.26	15.03	15.03
V_2^*	12.31	32.75	32.09	36.89	36.44

Assumptions

- VP = VP_2 (assumption: All VP convert into VP_2)
- E5 = E4 (Same defect but different charge state)
- $V_{2(=/-)}$ = $V_{2(-/0)}$ (Same defect but different charge state)
- V_2^* = (Deep peak) – (VP + E5 + V_2)

Clustering is responsible for low VP because there are fewer single vacancies available to form VP

Conclusions

- We simulate neutron displacement damage in pnp Si BJTs using five different mass particles: electrons, He, O, Si and Au ions
  - He irradiations produce more VP defects compared to O, Si and Au irradiations for match gain degradation conditions
  - Clustering is responsible for low VP because there are fewer single vacancies available to form VP
  - Clustering defects such as E5 are responsible for gain degradation, not VP

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