

Improving Charge Carrier lifetime and mobility in Hyperdoped Silicon by Seed Quality Engineering

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Motivation

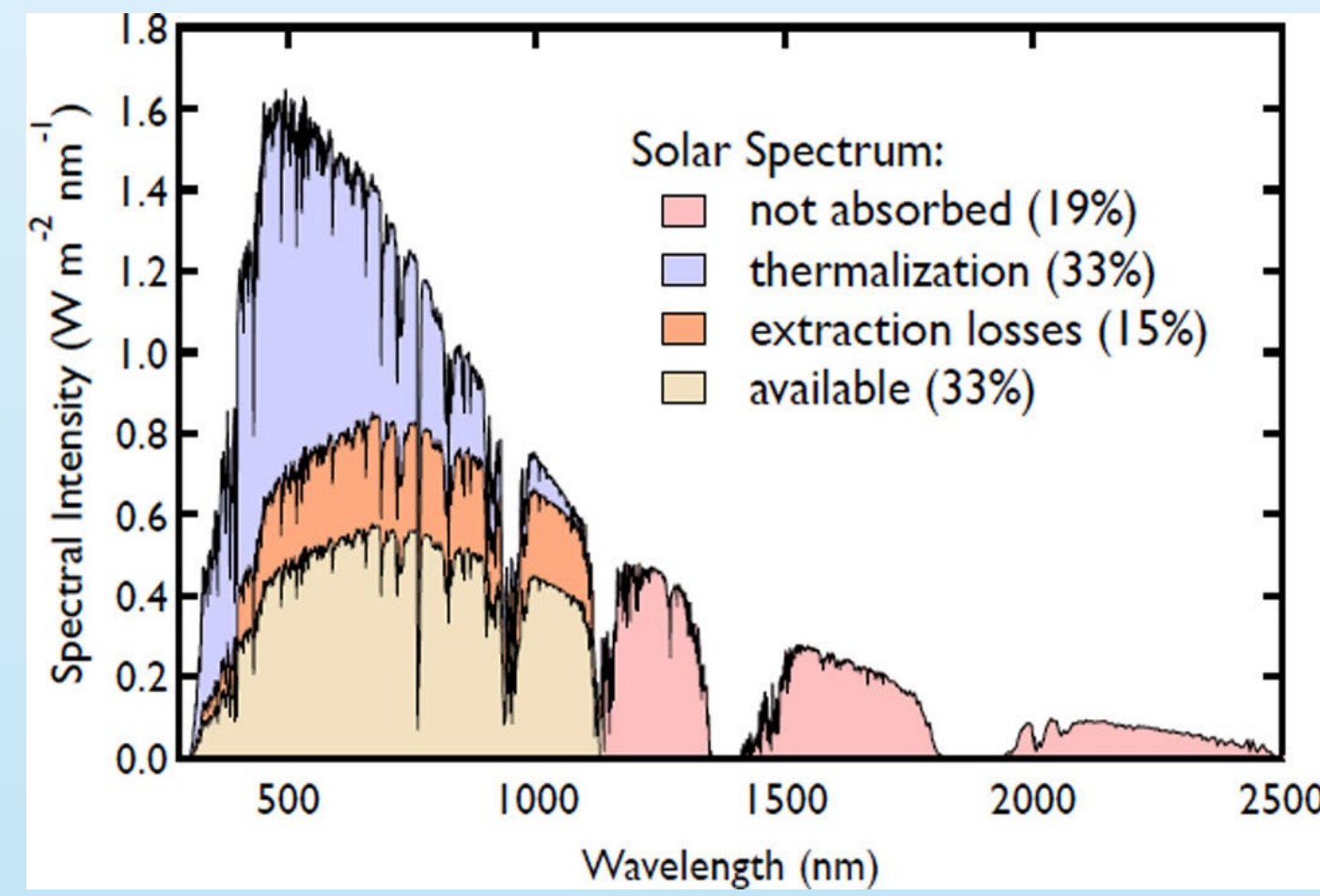


Fig. 1: Solar spectrum Vs wavelength and different losses regions in a silicon device. [1]

Fig. 2: Multiphoton absorption process in IBSC. [2]

The performance of silicon-based solar cell can be improved by utilizing a wider range of the solar spectrum. This can be obtained by introducing an intermediate band (IB) in the band structure. Two lower energy photons are absorbed in two steps, producing one high energy electron. Hyperdoping is a promising method to incorporate large concentration of dopants and enabling IB formation.

Hyperdoping

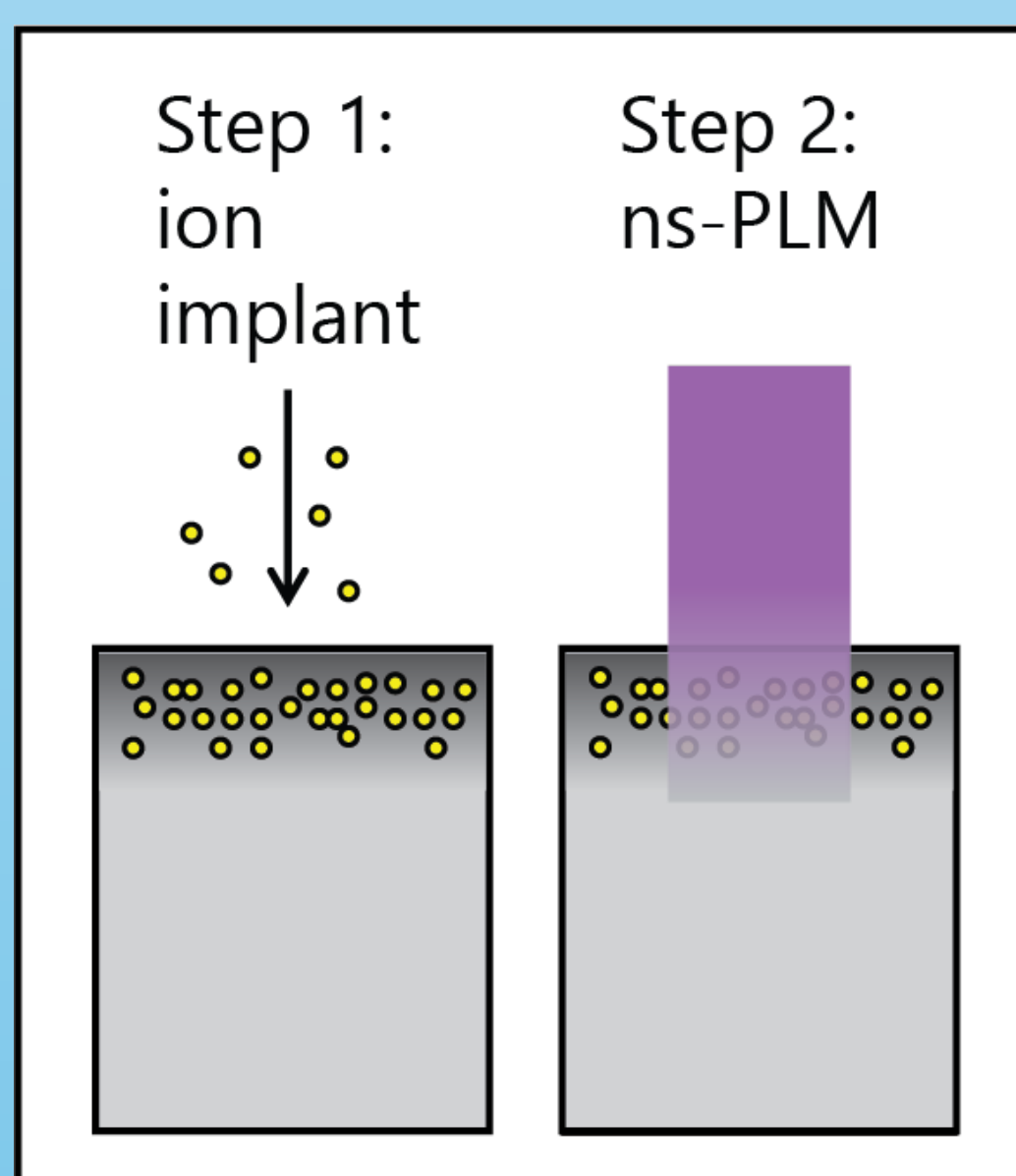


Fig. 3: Two Steps of Hyperdoping. [3]

- Step 1, high dose of dopant ions are implanted in Si which results in structural damage.
- Step 2, a ns-laser pulse melts the damaged Si, which then regrows epitaxially from the seed that is the underlying crystal.
- Although the PLM process removes most structural damage and resulting material is single crystalline, both PLM induced defects and ion implantation defects are detected in the processed material. [4]

References

- [1] O. Semonin et al., Ph.D. thesis, University of Colorado Boulder (2012)
 [2] S. Dissanayake et al., Ph.D. thesis, Wesleyan University (2022)
 [3] M. Sher et al., Semicond. Sci. Technol. 38, 033001 (2023)
 [4] S. Coffa et al., J Appl Phys 81, 1639 (1997)

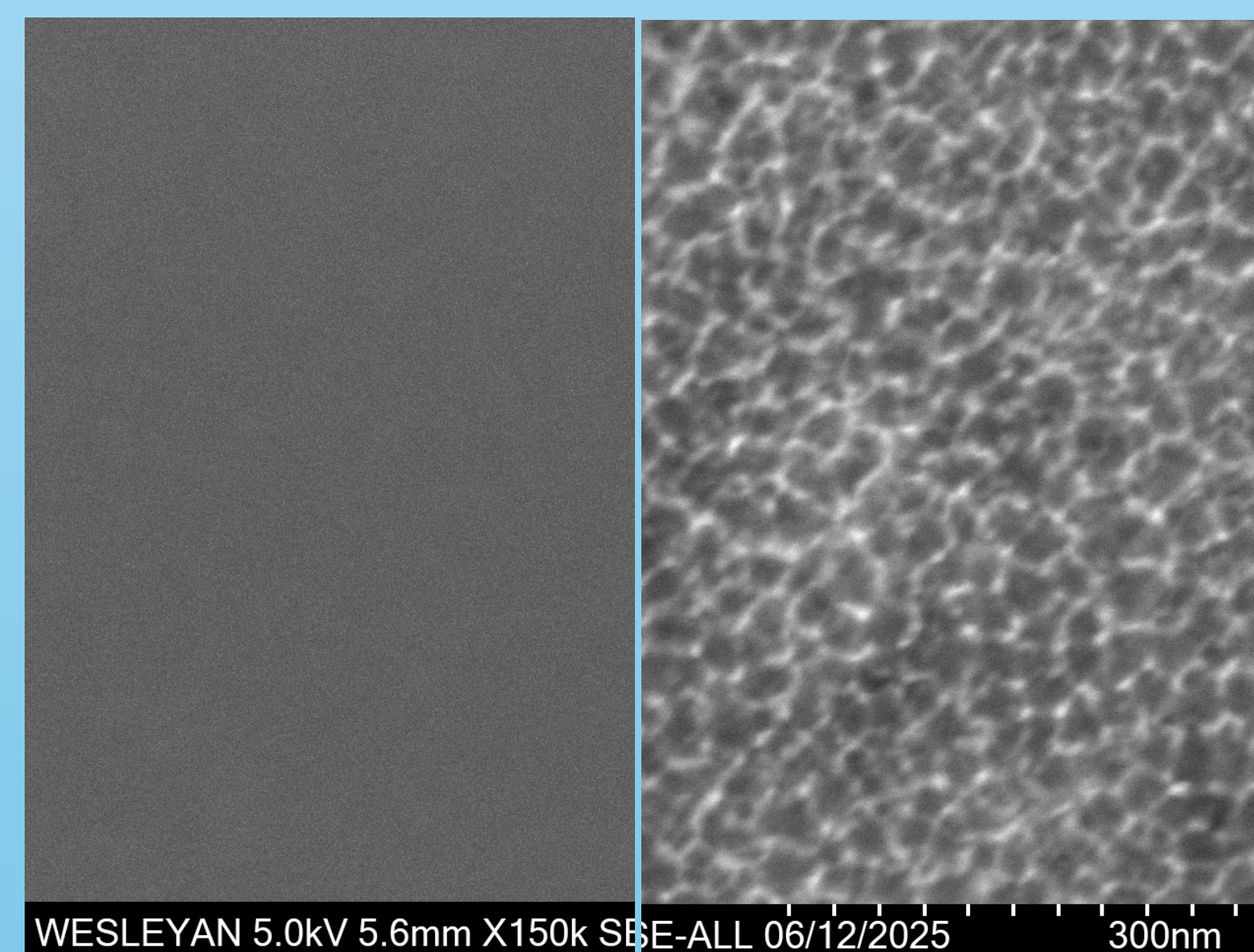


Fig. 4: SEM images of Si:Au pre-annealed at 350 °C (left) and cellular breakdown in another Si:Au (right).

Two ways to improve HD-Si

1. Increasing the PLM melt depth
2. Pre-annealing before the PLM process

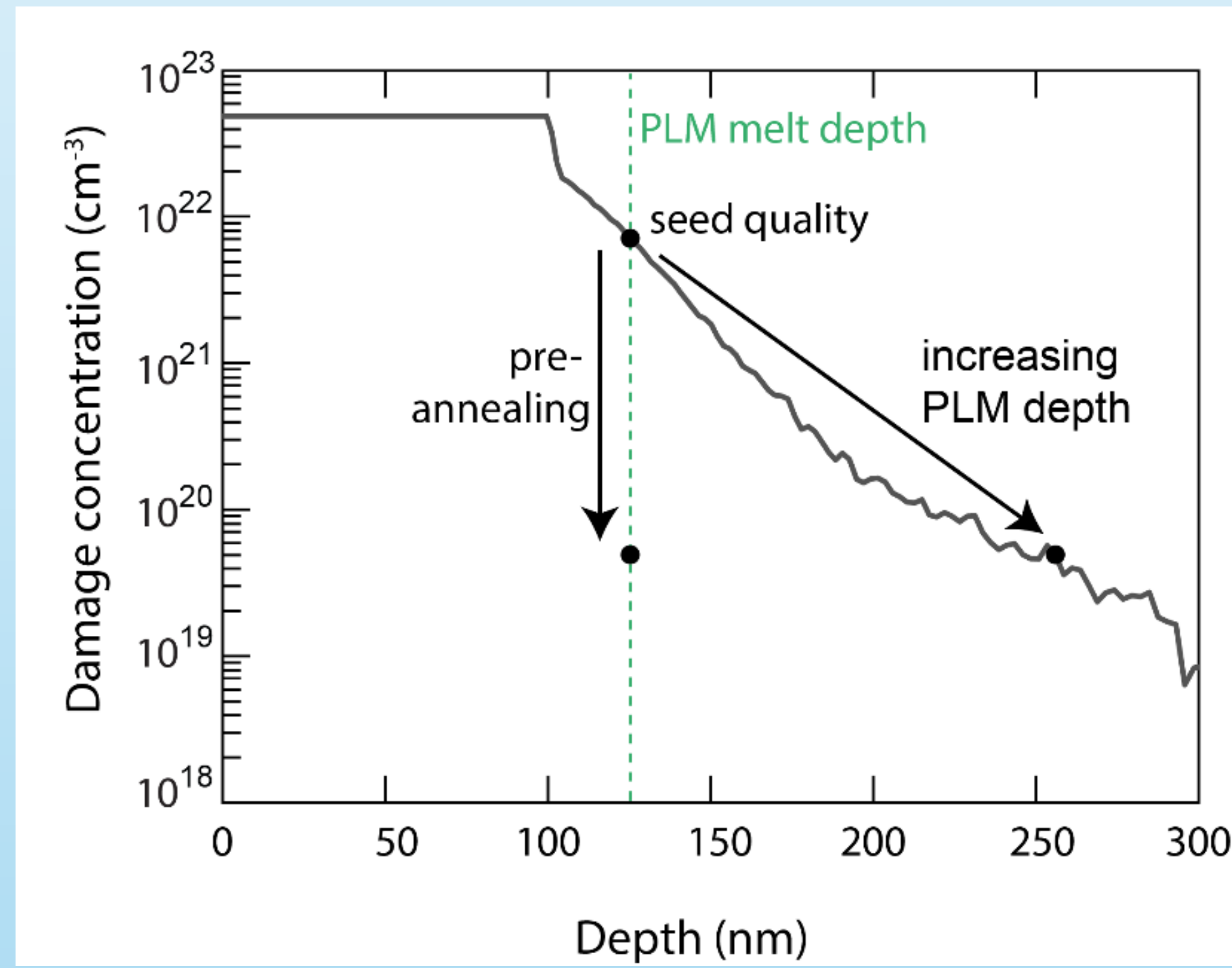


Fig. 5: Damage concentration as a function of material's depth after ion implantation.

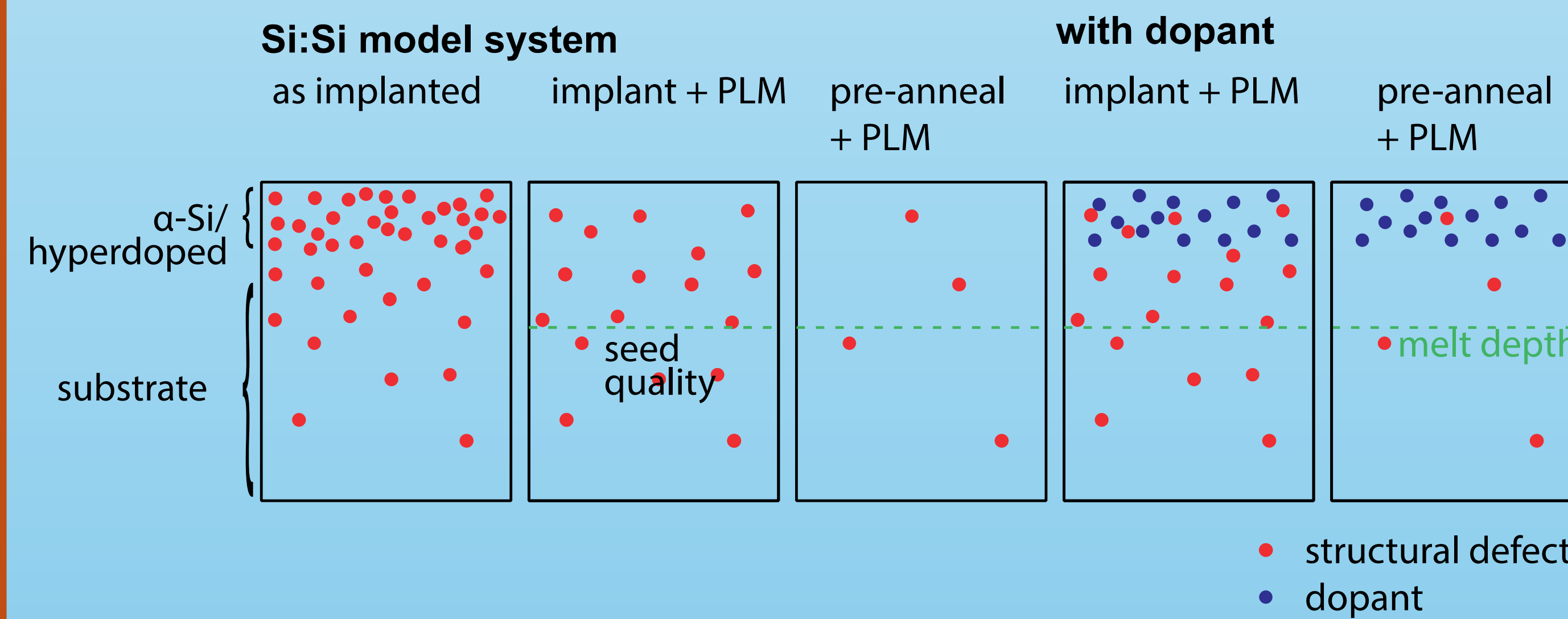


Fig. 6: Structural defects and dopant distribution in Si self implanted system and implanted with dopant in two conditions: without pre-annealing and with pre-annealing.

Experiment

Time Resolved Terahertz (THz) Spectroscopy (TRTS), a non-contact photoconductivity measurement, is used to determine the carrier dynamics.

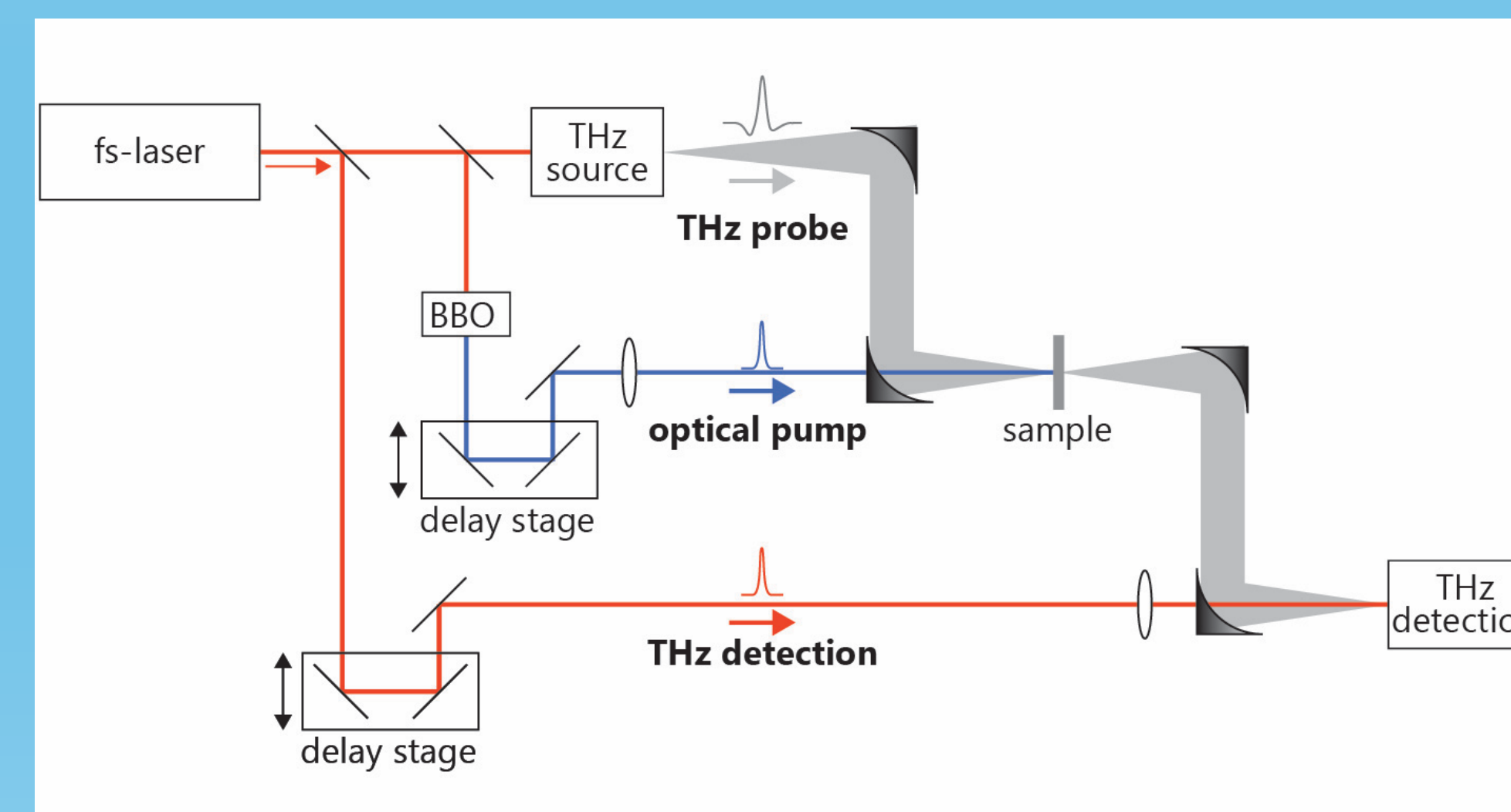


Fig. 7: Schematic of experimental setup

The optical pump pulse excites the carriers within the material, and the subsequent THz probe pulse measures the change in the transient conductivity of the material.

Result of increasing melt depth

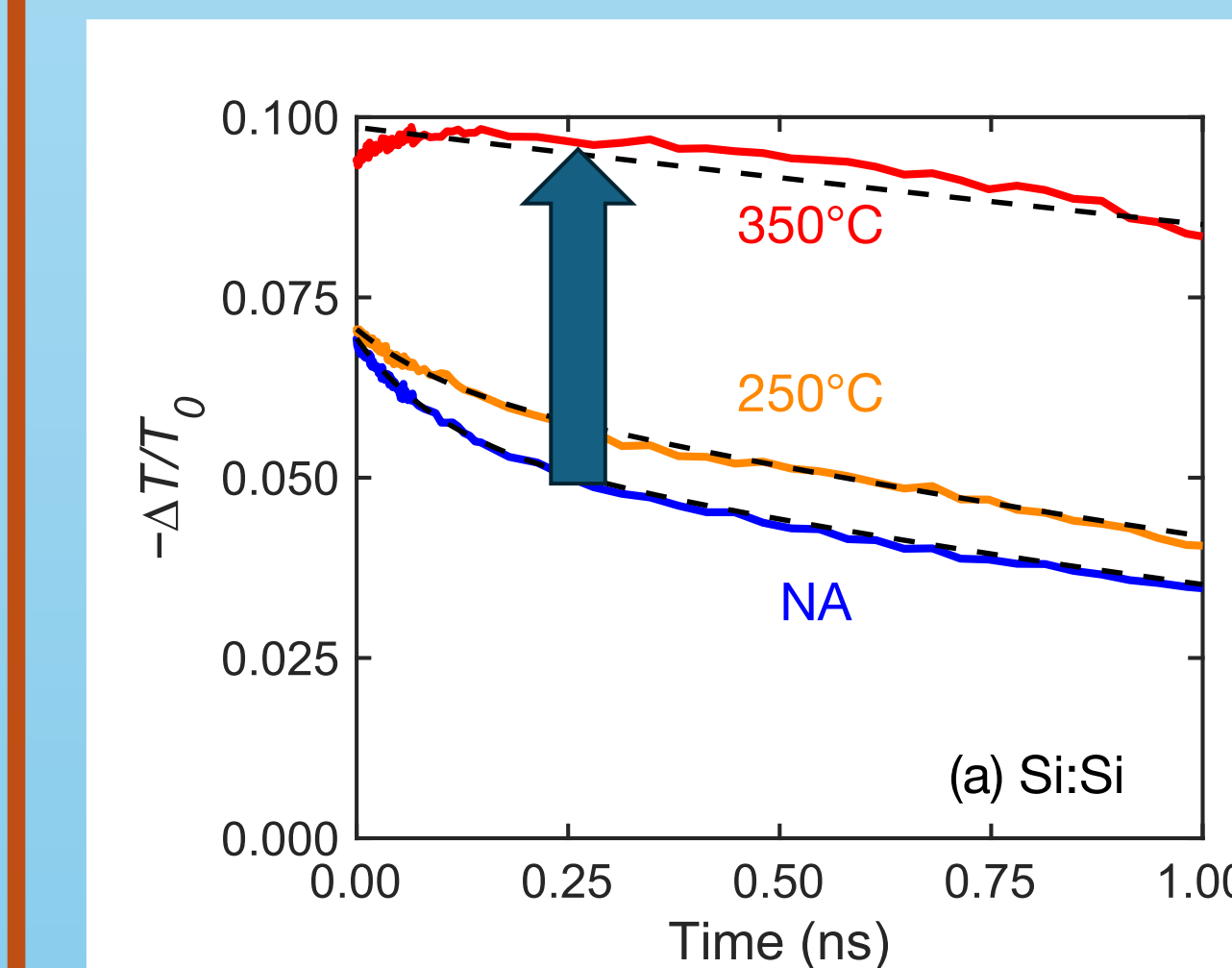
We observe the carrier decay dynamics of Si self implanted with Si (Si:Si), Si implanted with Te (Si:Te) and Si implanted with Au (Si:Au) at 400-nm photoexcitation.

- For Si:Si, half-life of the transient photoconductivity improves from 20 to 833 ps with increasing PLM melt depths.



Fig. 8: Normalized transient photoconductivity measurement of the Si:Si model system at various PLM melt depths

Results of introducing pre-annealing



With increasing pre-annealing temperature:

- For Si:Si, lifetime improves from 2.2 to > 4 ns (detection limit) and mobility improves 1.3 times.
- For Si:Te, lifetime improves from 2.5 to > 4 ns and mobility improves 2 times.
- For Si:Au, limited lifetime improves from 0.8 to 0.9 ns and mobility improves 1.1 times.

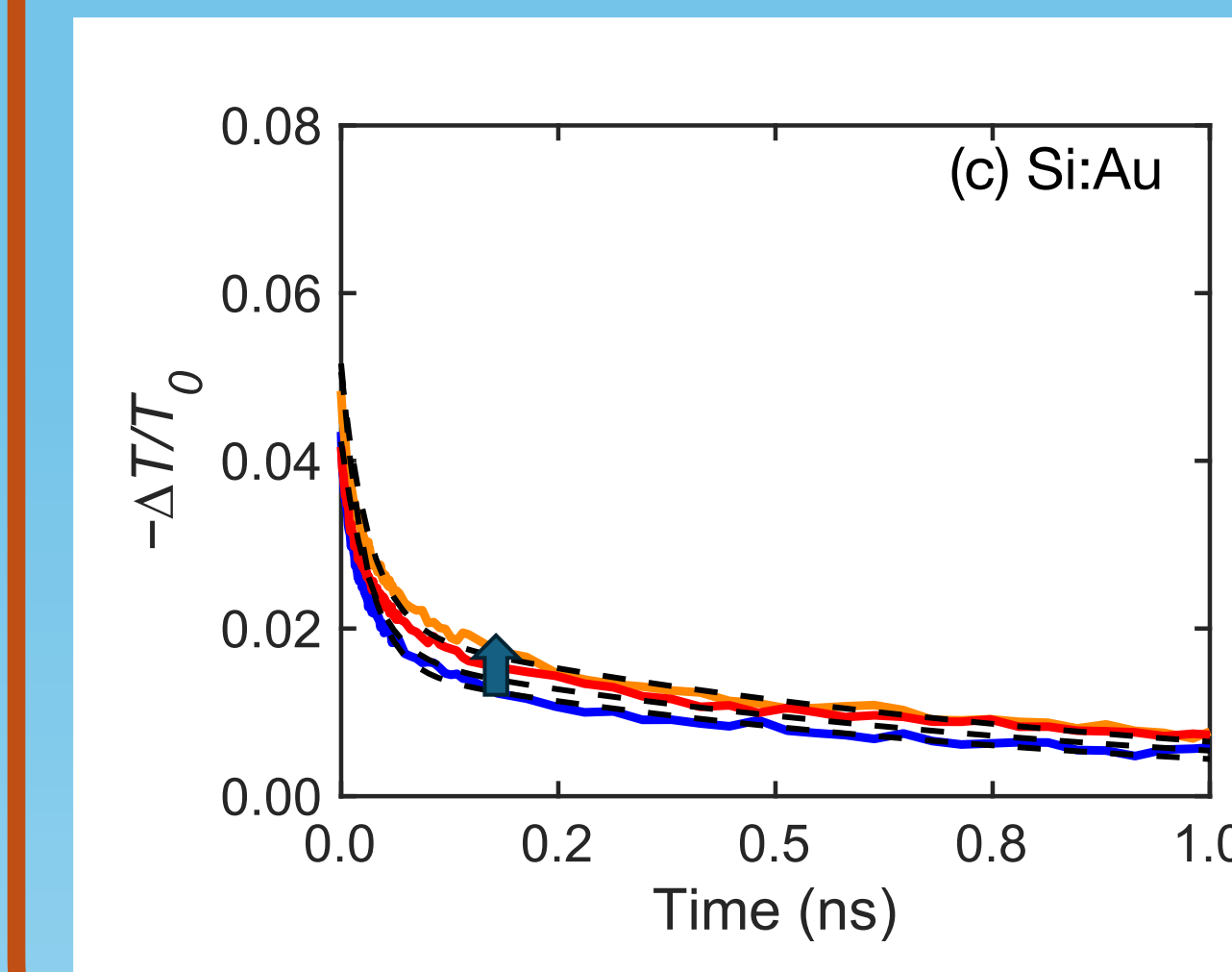
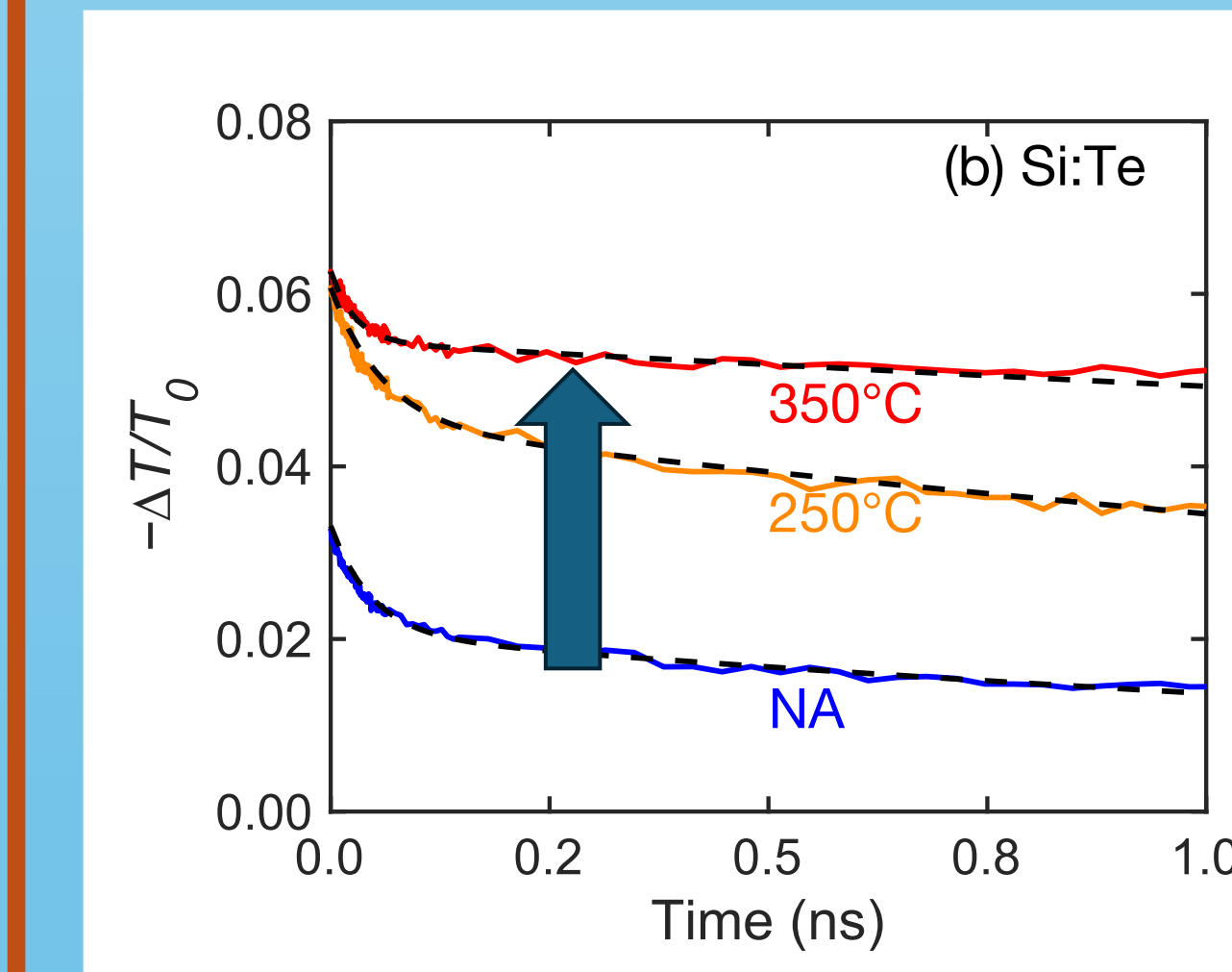


Fig. 9: Carrier decay dynamics of (a) Si:Si, (b) Si:Te and (c) Si:Au

Conclusion

- By increasing PLM melt depths, the carrier lifetime and mobility improves.
- After adding pre-annealing step in the fabrication process of hyperdoping, the carrier lifetime and mobility improves.
- Dopant-defect interaction limits the improvement in pre-annealing.