シリコン表面パッシベーションの実時間観察
～欠陥とバンドオフセットの効果～

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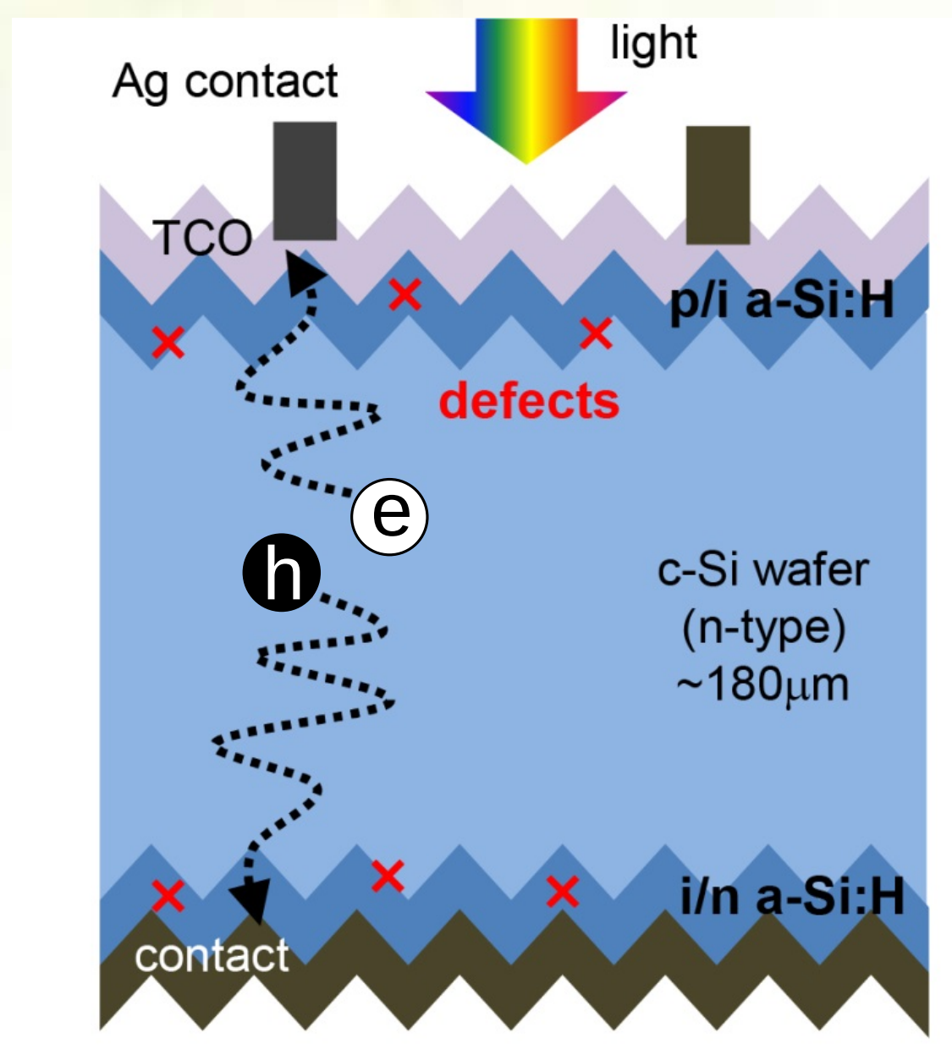
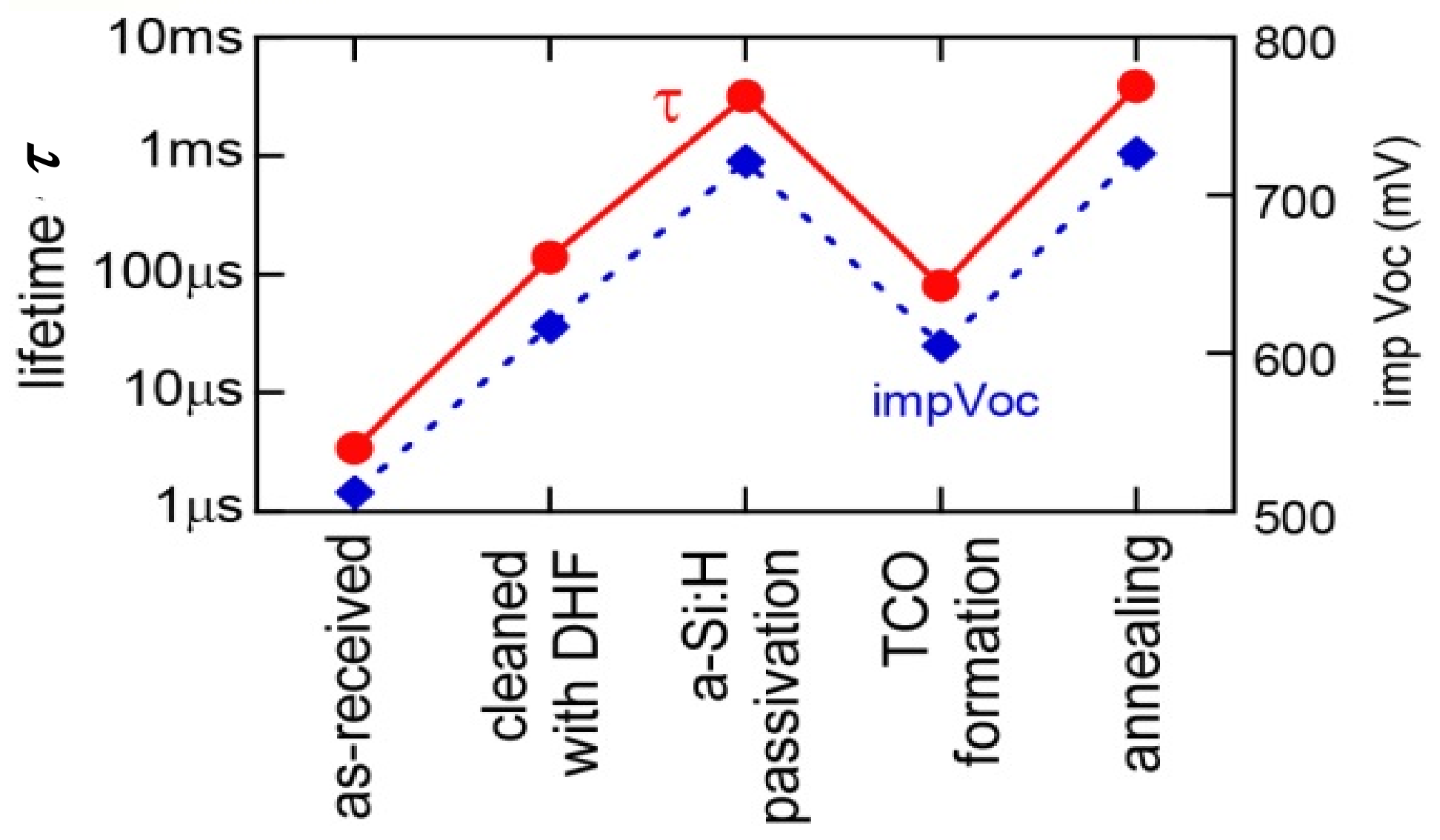
Abstract

- **Surface passivation of crystalline silicon (c-Si)** is studied during growth of a hydrogenated amorphous silicon (**a-Si:H**) and epitaxial silicon (**epi-Si**) passivation layer at subnanometer to nanometer scale.
- The passivation is improved by the growth of an a-Si:H layer, where **a large band offset** is formed at the a-Si:H/c-Si interface.
- The passivation is deteriorated with the growth of an epi-Si, because the band offset is not formed at the interface, and **plasma-induced defects** are created in c-Si.

SHJ solar cell, interface defects and carrier lifetime

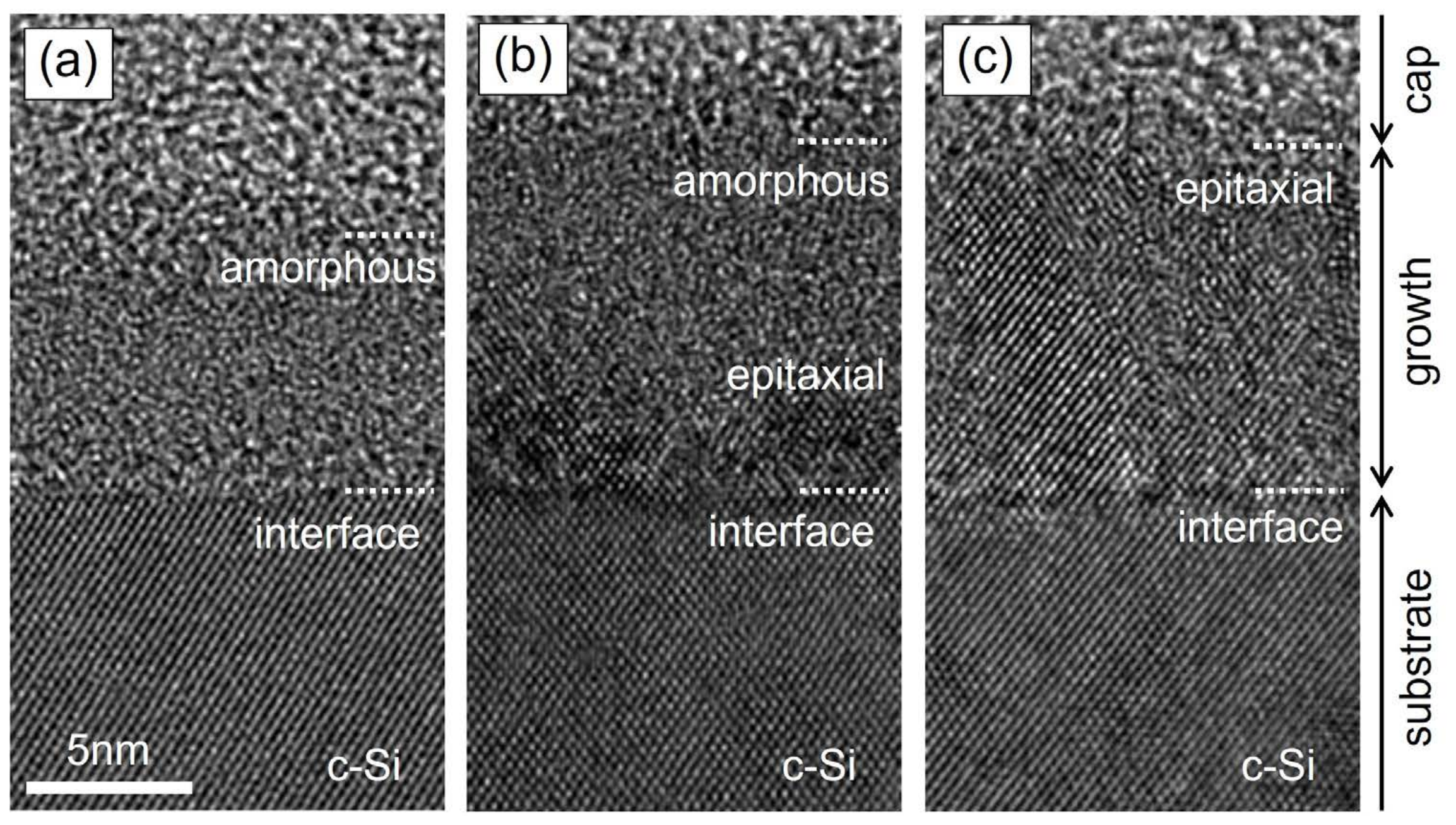


- In silicon heterojunction (SHJ) solar cells, a-Si:H layer plays important roles in surface passivation & carrier selection.



- The carrier lifetime, i.e., a measure for the surface passivation, varies throughout the fabrication process of SHJ solar cells.

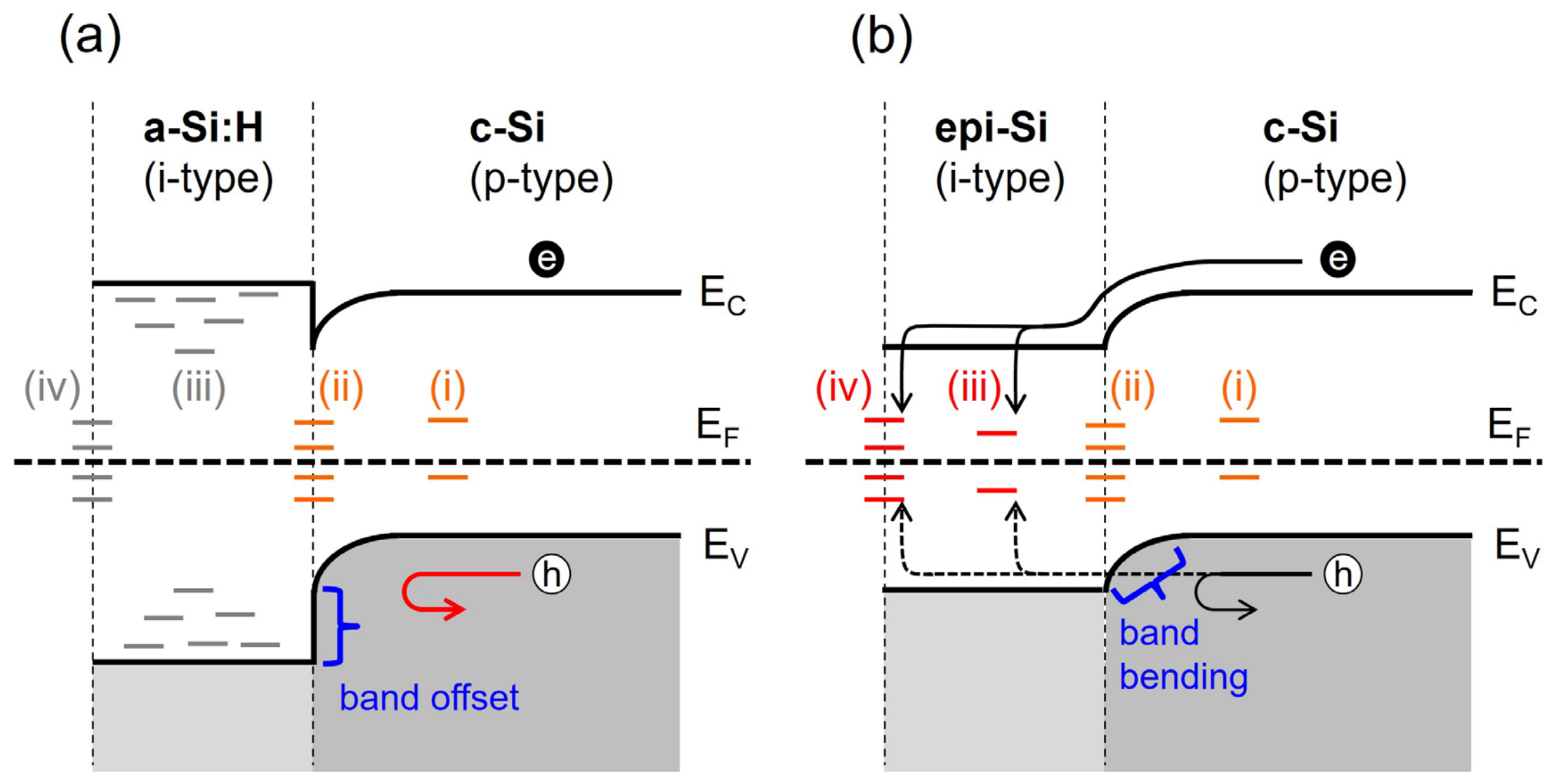
a-Si:H and epi-Si growth on SOI



- Cross-sectional TEM images of passivation layers grown over SOI at different hydrogen (H_2)-dilution of (a) D = 0, (b) D = 5, and (c) D = 20.
- (a) An **a-Si:H layer** is grown over the SOI. (b) An **epi-Si layer** is initially grown in a few nm, and then an a-Si:H layer is grown over the epi-Si layer. (c) An epi-Si layer is grown from the bottom to the top of the passivation layer.

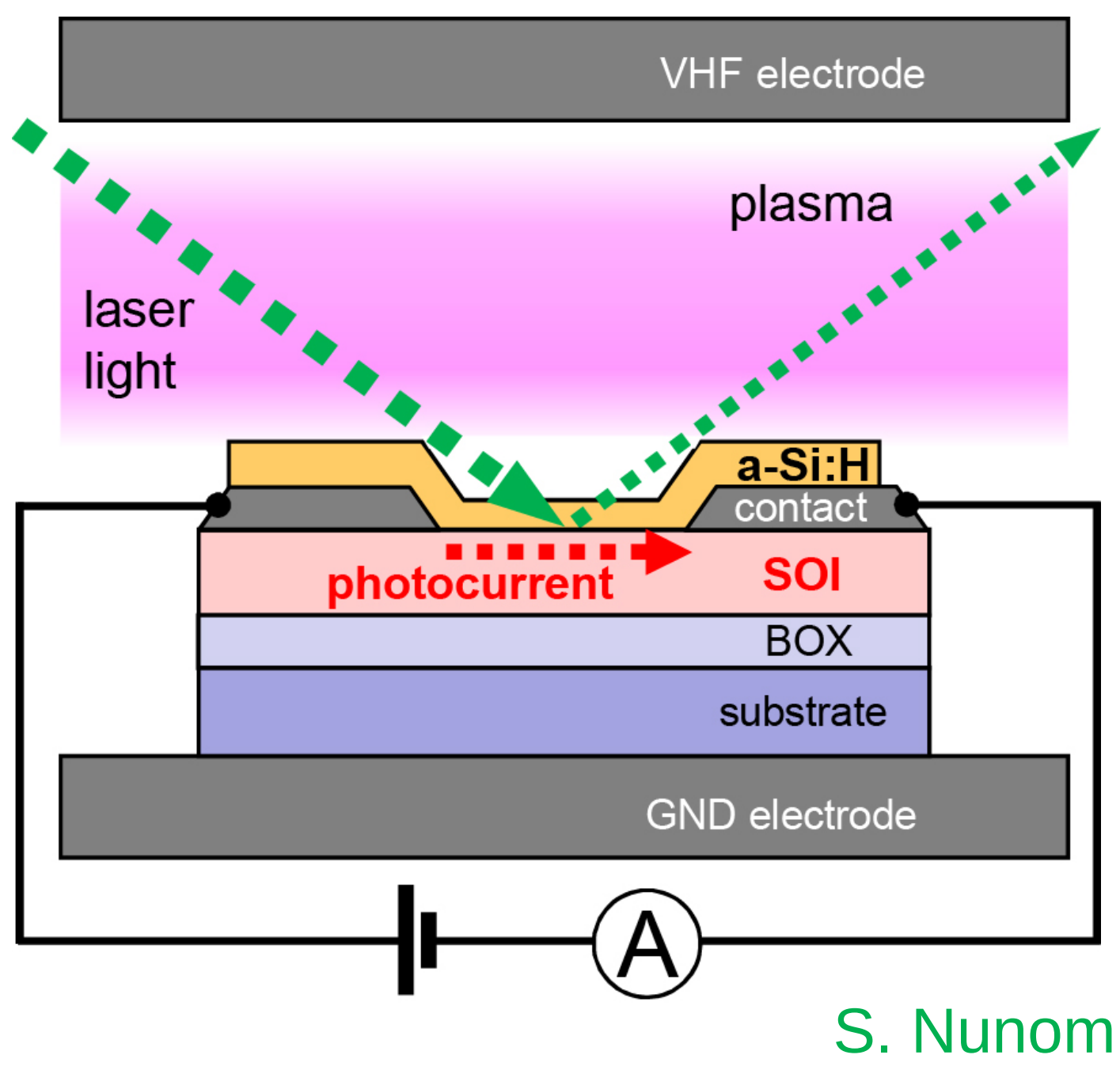
S. Nunomura et al., J. Appl. Phys. 128, 033302 (2020).

Model: band diagram, defect levels & carrier dynamics



- (a) a-Si:H / p-type c-Si and (b) i-type epi-Si / p-type c-Si.
- **The recombination centers** are classified into four groups, depending on the location of defects: (i) **bulk Si defects**, (ii) **interface defects**, (iii) **bulk a-Si:H** or **epi-Si defects**, and (iv) **surface defects**.
- In the a-Si:H/c-Si stack, the carrier recombination is dominated by the recombination centers located at the interface and in bulk Si, denoted by (ii) and (i) respectively. In the epi-Si/c-Si stack, the carrier recombination comes from not only at above two centers, but also the recombination centers located in the epi-Si bulk and surface, denoted by (iii) and (iv).

Exp. setup: in-situ real-time photocurrent measurement

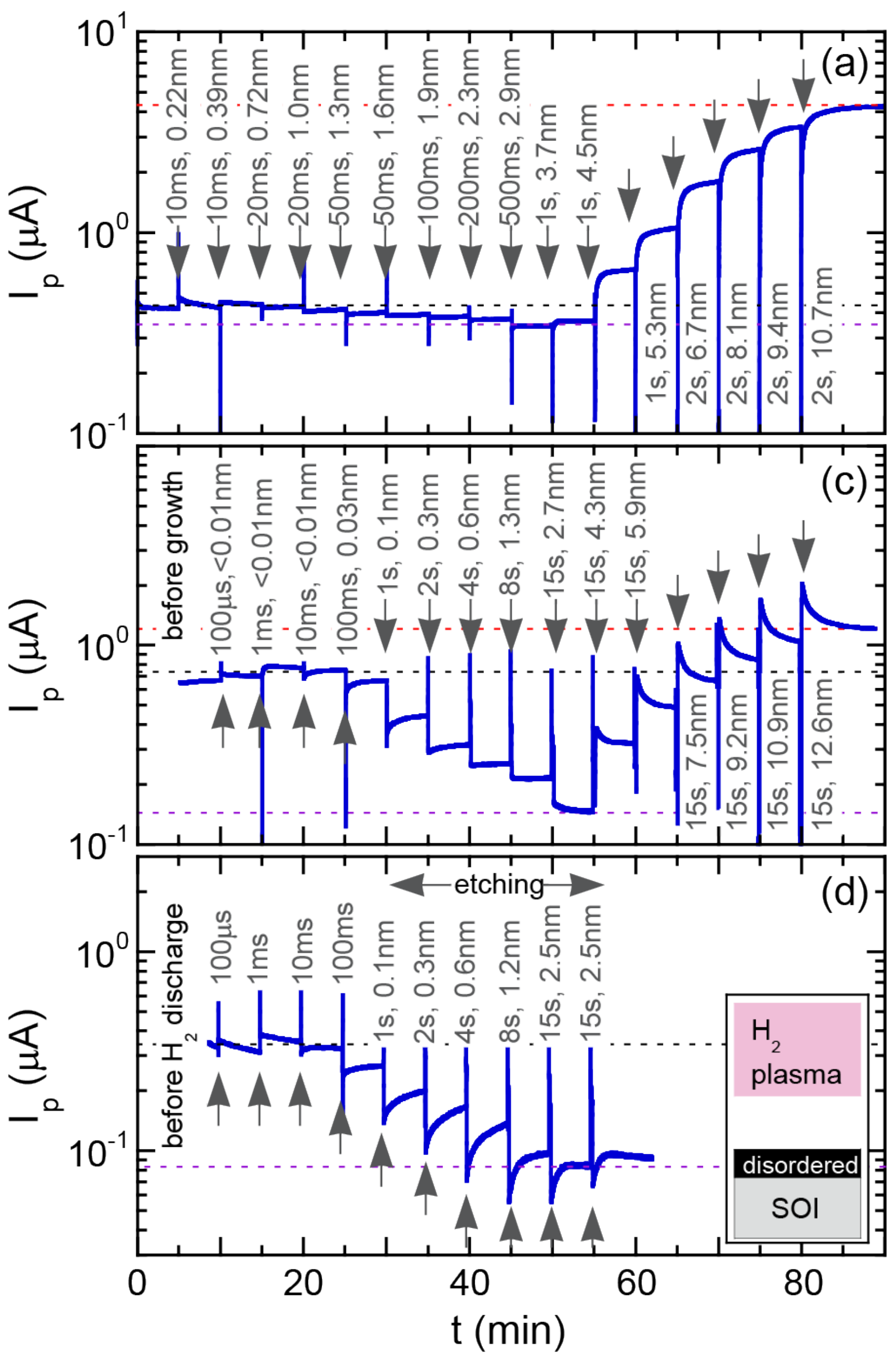


- **Silicon on insulator (SOI)** is used as a sample for the photocurrent measurement.
- SOI is illuminated with a **semiconductor laser** (520nm, 1mW).
- The **photocurrent** is measured during plasma proccessing and subsequent postannealing.
- In experiments, **the treatment time (Δt)** and **temperature (T)** are varied.

S. Nunomura et al., *Appl. Phys. Express.* **12**, 051006 (2019).

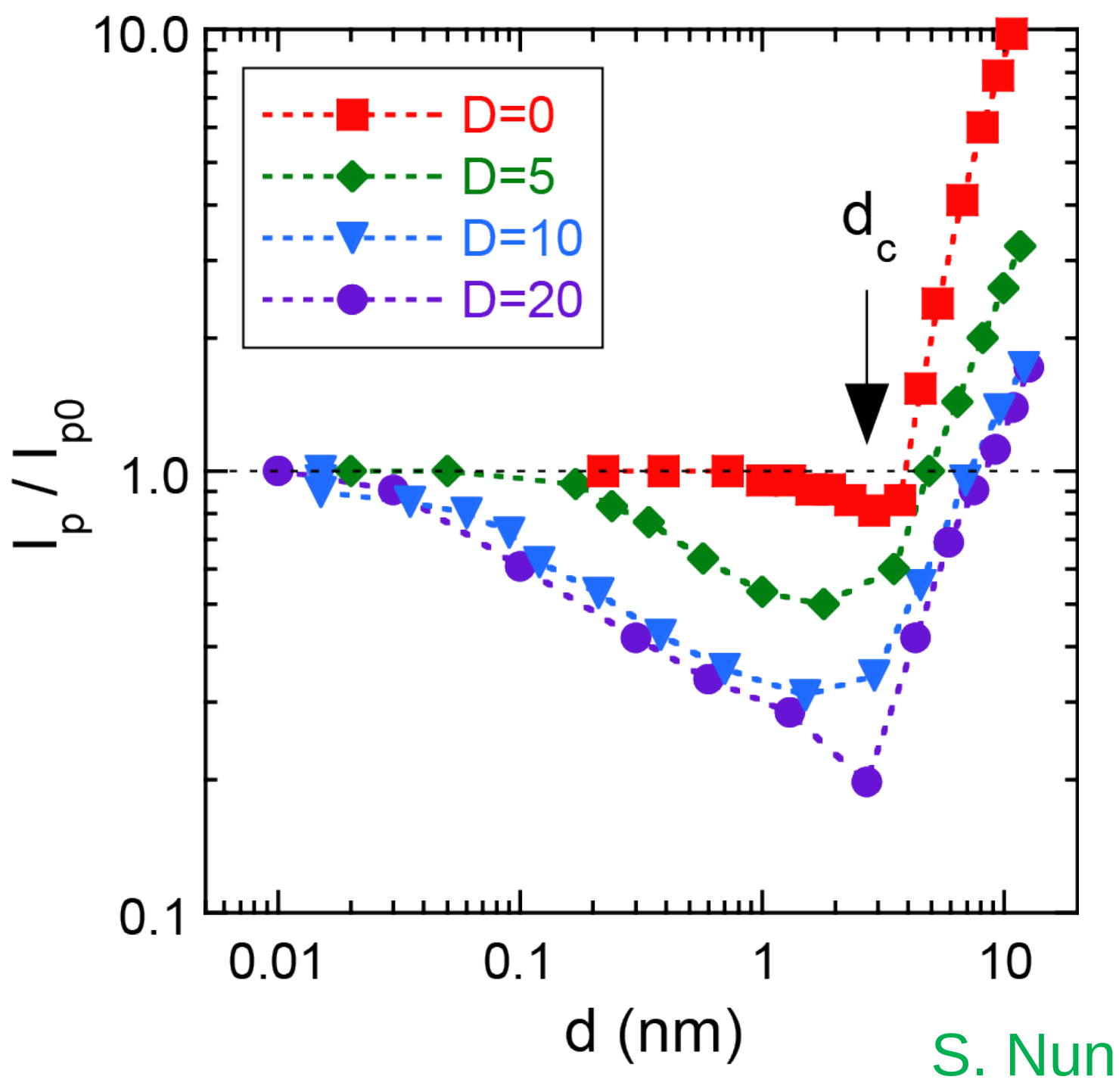
Experimental results

Time evolution of photocurrents



- Time evolutions of photocurrents, I_p, in SOI during growth and consecutive annealing at (a) D = 0 and (c) D = 20. For comparison, the time evolution of I_p for H_2 plasma treatments is shown in (d).
- **I_p initially exhibits a decreasing tendency** for a series of growth of an ultrathin, and then **it exhibits an increasing tendency** for growth of a relatively-thick layer.
- **The decreasing tendency reflects the deterioration of the passivation.**
  => "defect formation"
- **The increasing tendency reflects the improvement of the passivation.**
  => "defect annihilation"

Photocurrent & passivation / deterioration



- I_p/I_{p0} is reduced with d for an ultrathin layer (d < 2.5 nm), whereas it is increased with d for a thick (d > 2.5 nm).
- **The reduction in I_p/I_{p0} is enhanced for a high-D case.**
- The change from the decreasing to the increasing tendency of I_p/I_{p0} takes place in a range of ~2.5 nm, implying the carrier diffusion length.

S. Nunomura et al., J. Appl. Phys. 128, 033302 (2020).

Summary

- **The surface passivation of c-Si** is experimentally studied during growth of an a-Si:H and epi-Si layer by using in-situ real-time photocurrent measurement technique.
- The passivation is maximized for an a-Si:H layer growth, due to the formation of **a large valence band offset** and **band bending** near the interface between the a-Si:H layer and the SOI. The field effect plays an important role in the passivation.
- The passivation is deteriorated with an epi-Si layer growth, because the **H-mediated bulk Si defects** are formed. Besides, the **band bending is not fully formed** near the epi-Si/SOI interface.

Acknowledgements

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