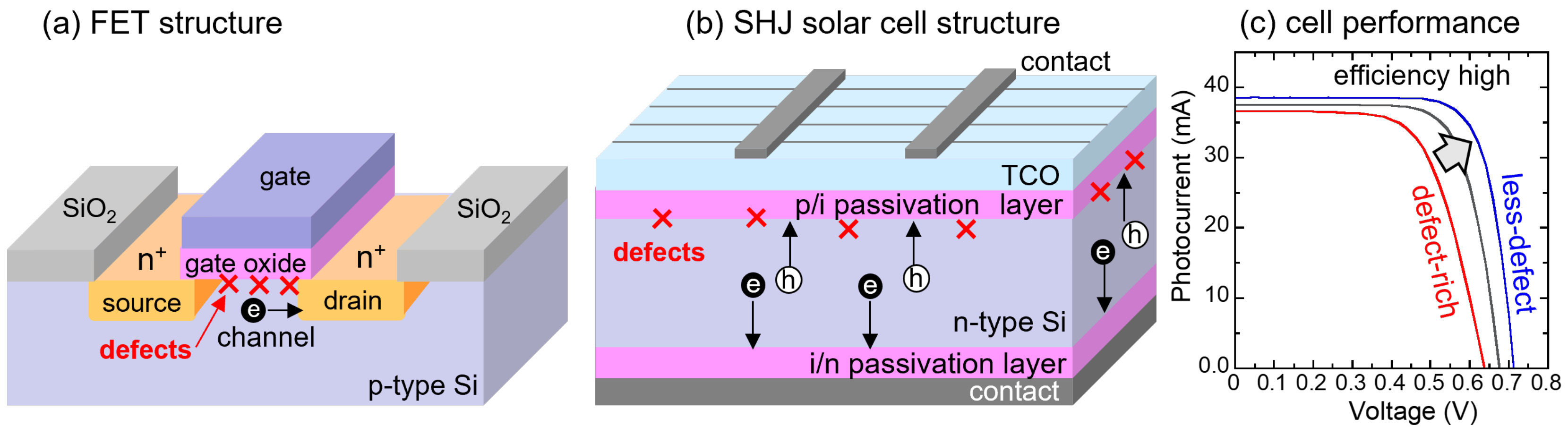
# 太陽電池向けシリコンの表面パッシベーション：
## プラズマプロセスに伴うパッシベーション膜の構造変化と欠陥のその場評価

## Abstract

- **A beneficial effect** of **argon (Ar) ion bombardment** for **crystalline silicon (c-Si) surface passivation** has been studied.
- Experiments of an Ar plasma treatment over a **hydrogenated amorphous silicon (a-Si:H)** layer on c-Si are performed.
- The c-Si surface passivation is improved by an Ar plasma treatment for a **defect-rich, i.e., low-quality**, a-Si:H layer, while it is deteriorated by the treatment for a **low-defect, i.e., high-quality**, a-Si:H layer.

## Introduction: Device, defects, and performance


(a) FET structure

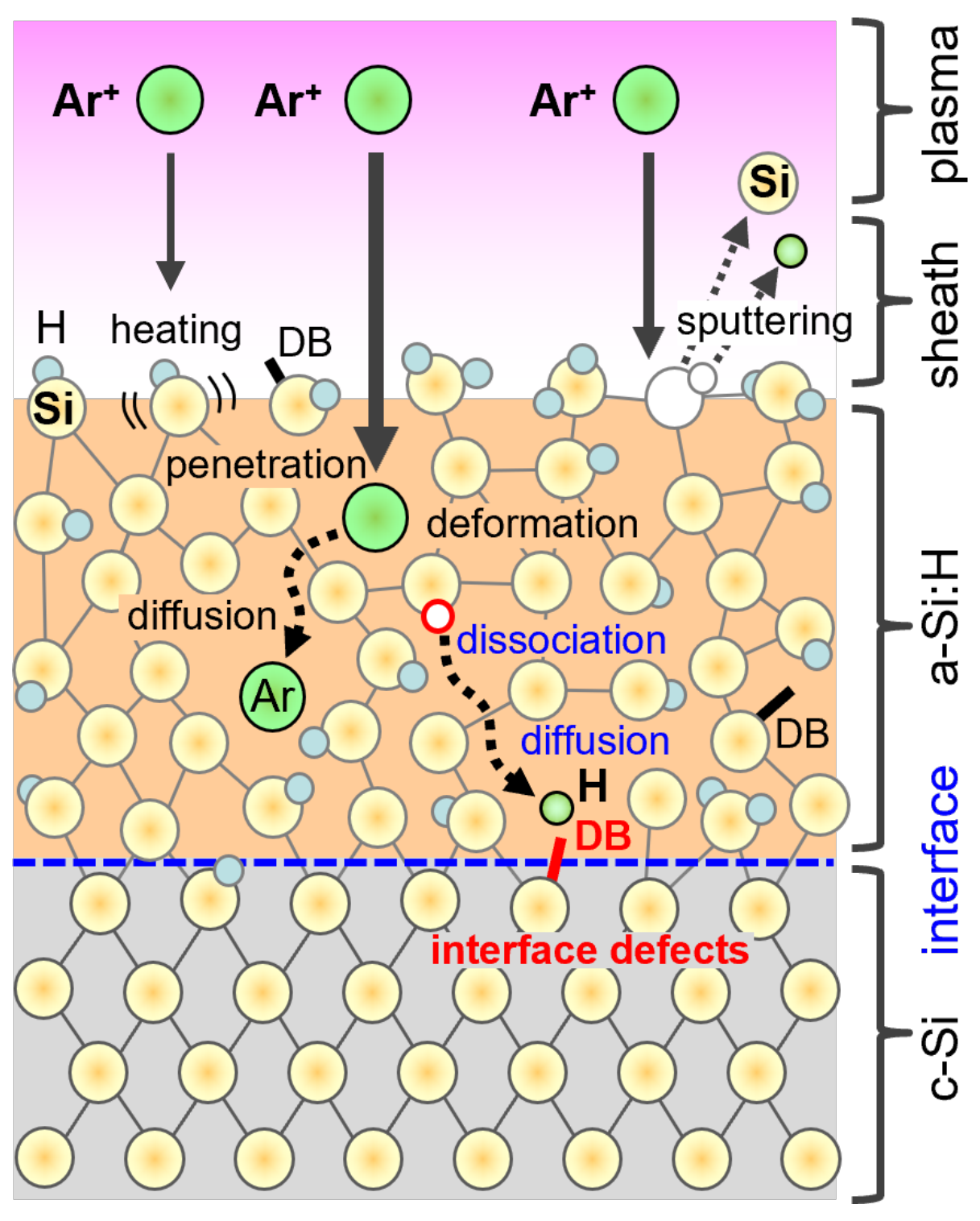
(b) SHJ solar cell structure

(c) cell performance

- The **defects** in semiconductors impact on the device performance & reliability.
- In **field-effect transistor (FET)**, defects at the channel-gate interface induce the deterioration of the carrier transport and current leakage.
- In **solar cell** based on **silicon heterojunction (SHJ)**, defects formed at the heterointerface result in a decrease in the conversion efficiency via reductions in both the photocurrent and the output voltage.

S. Nunomura, *J. Phys. D: Appl. Phys.* **56**, 363002 (2023).

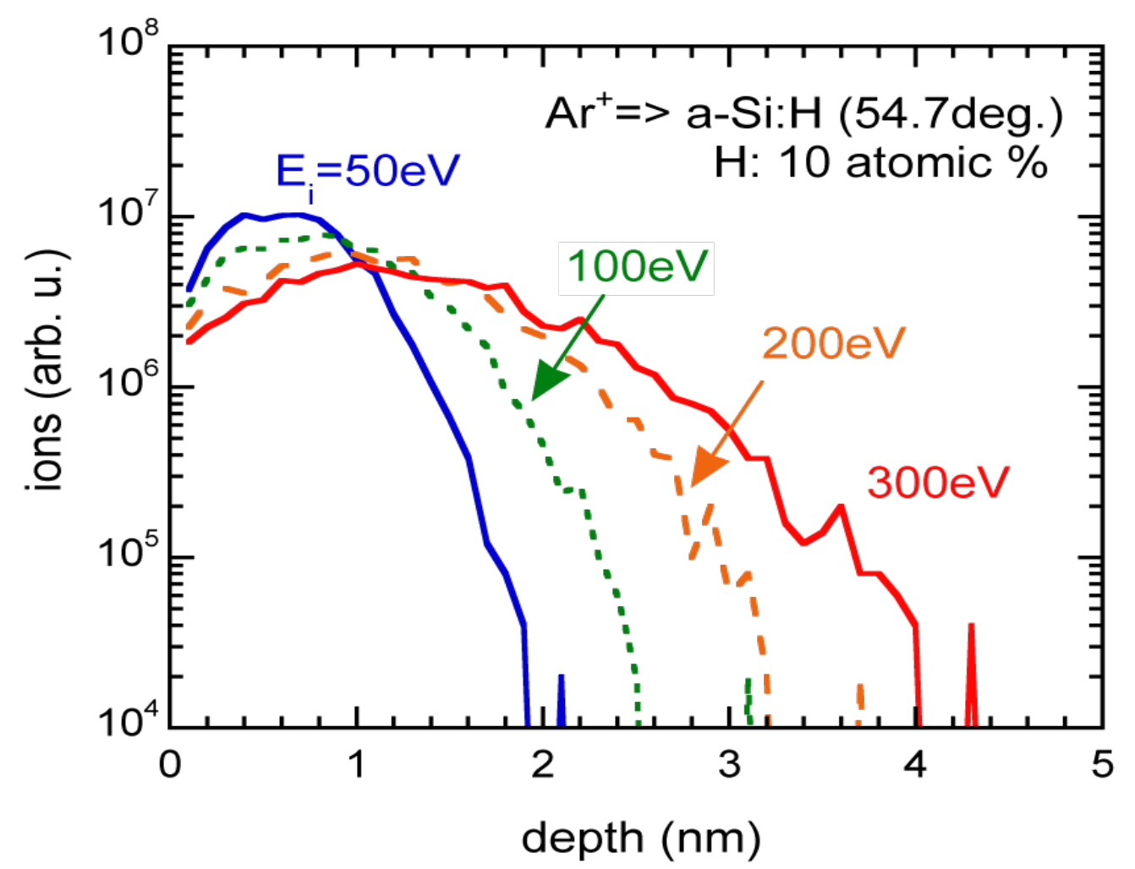
## Ion-material interactions for a-Si:H/c-Si heterostructure



- **The bombardments of Ar ions** induce surface heating and deformation of local network structure.
- The **heating and deformation** result in the bond breaking of weak Si-Si and Si-Hx, which results in **dangling bonds (DBs)** and **mobile hydrogen (H) atoms**.
- The **mobile H atoms** diffuse deeper and arrive at the a-Si:H/c-Si interface, where they terminate **the interface defects** such as DBs.

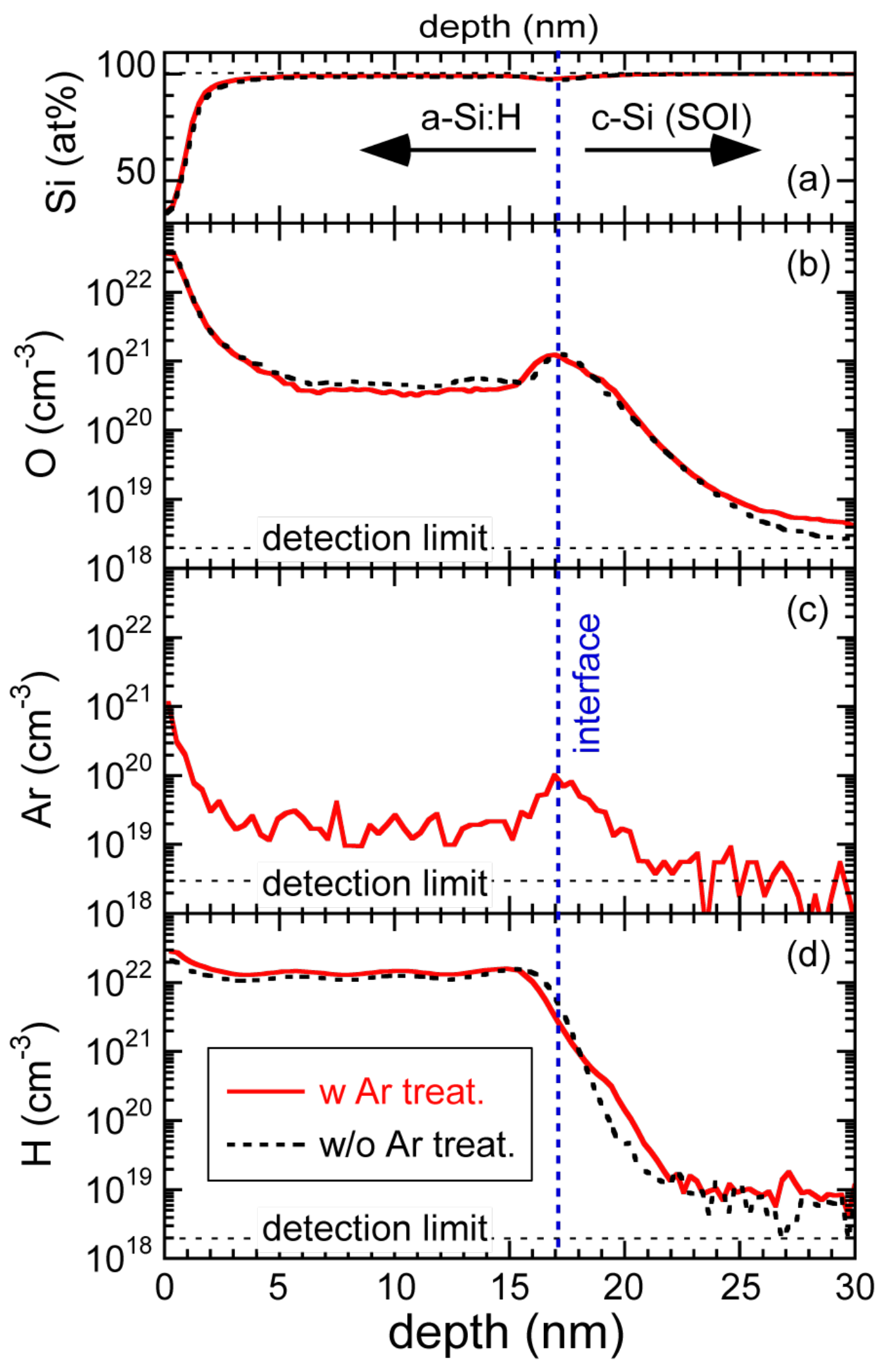
S. Nunomura et al., *J. Vac. Sci. Technol.* B **41**, 052202 (2023).

## Results: TRIM & SIMS analysis



- **Depth distribution** of Ar$^+$ implanted in a-Si:H (10 atomic percent H) for various incident energies.
- Ar ions are penetrated in **a few nm**.

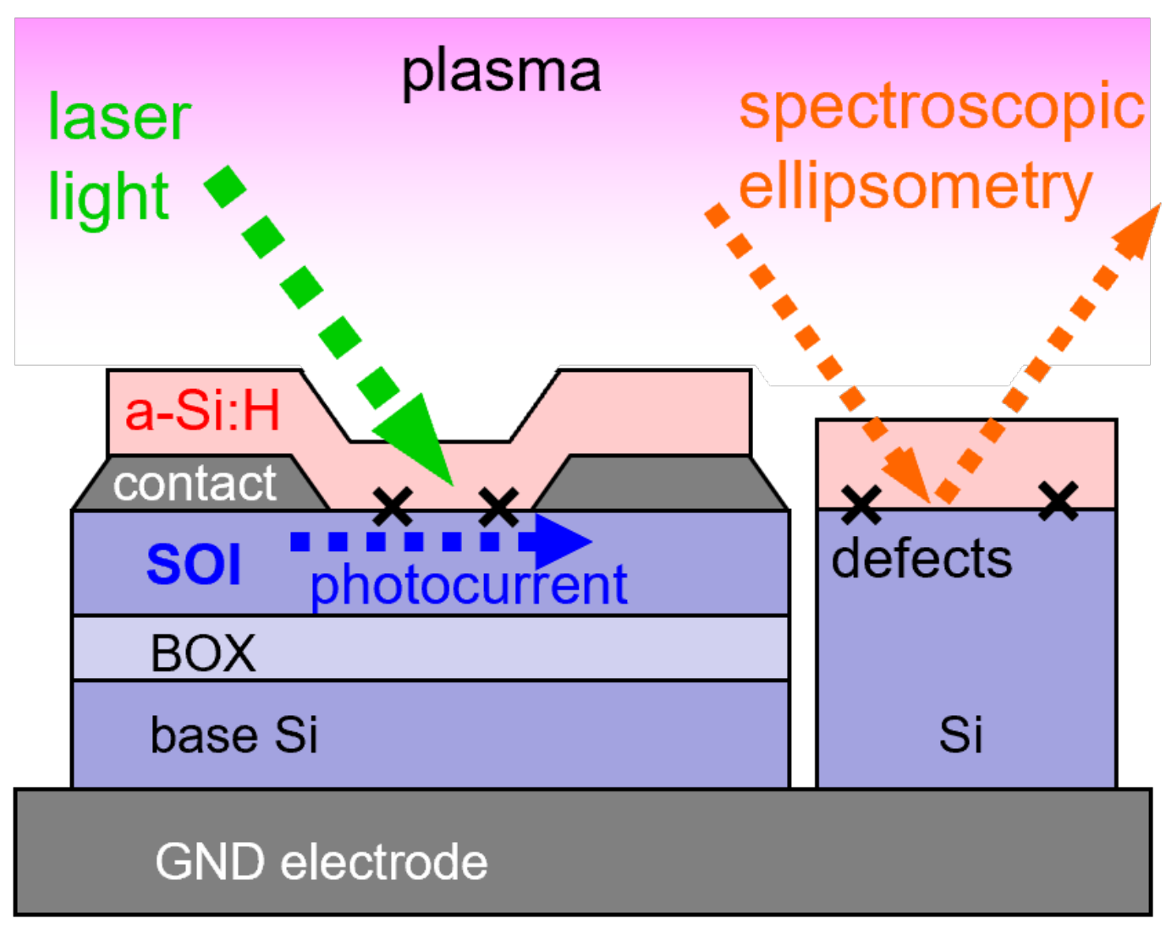
S. Nunomura et al., *Jpn. J. Appl. Phys.* **61**, 056003 (2022).



- Depth distribution of **Si, O, Ar and H** elements in a-Si:H/SOI, obtained by SIMS measurements.
- A black broken line shows the distribution for a sample without an Ar plasma treatment. A red solid line shows the distribution for a sample with an Ar plasma treatment of *P* = 50 W and *t* = 10 s.
- The **H distribution is broadened** at the a-Si:H/SOI interface by an Ar plasma treatment for a defect-rich a-Si:H prepared at $T_s$ = 80 ºC.
- The decay length of the H concentration is 1.04 nm for a sample with the Ar treatment, while it is 0.57 nm for a sample without the treatment.

S. Nunomura and I. Sakata, *Jpn. J. Appl. Phys.* **61**, 106001 (2022).

## Exp. setup: in-situ real-time characterization

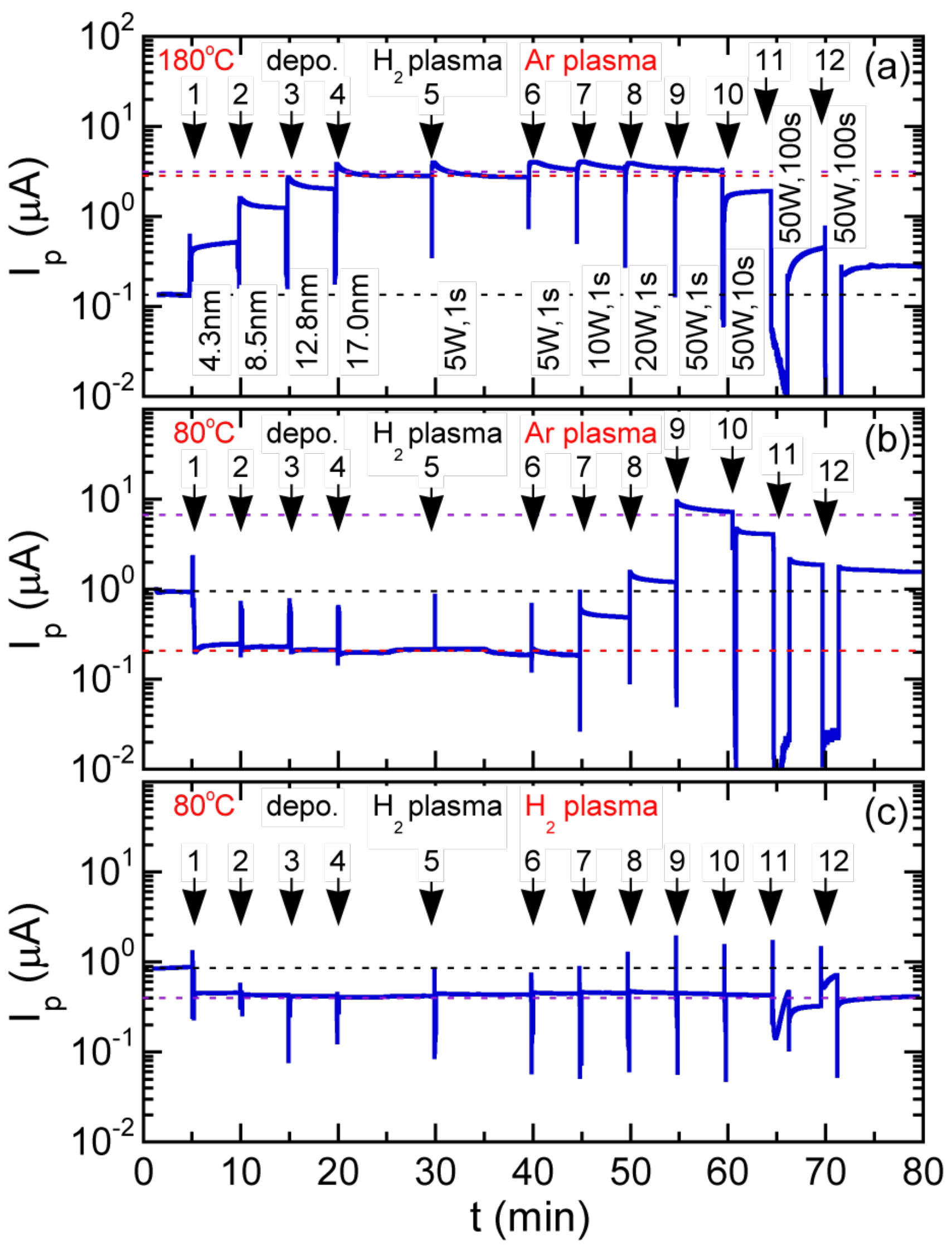


- **Silicon on insulator (SOI)** is used as a sample for the photocurrent measurement.
- SOI is illuminated with a visible light laser (520 nm, 1 mW).
- **In-situ photocurrent** measurement is performed to detect the defects at the a-Si:H/c-Si interface.
- **Real-time spectroscopic ellipsometry** is performed to obtain the thickness and optical parameters.

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

## Results: in-situ real-time characterization

### In-situ photocurrent measurements



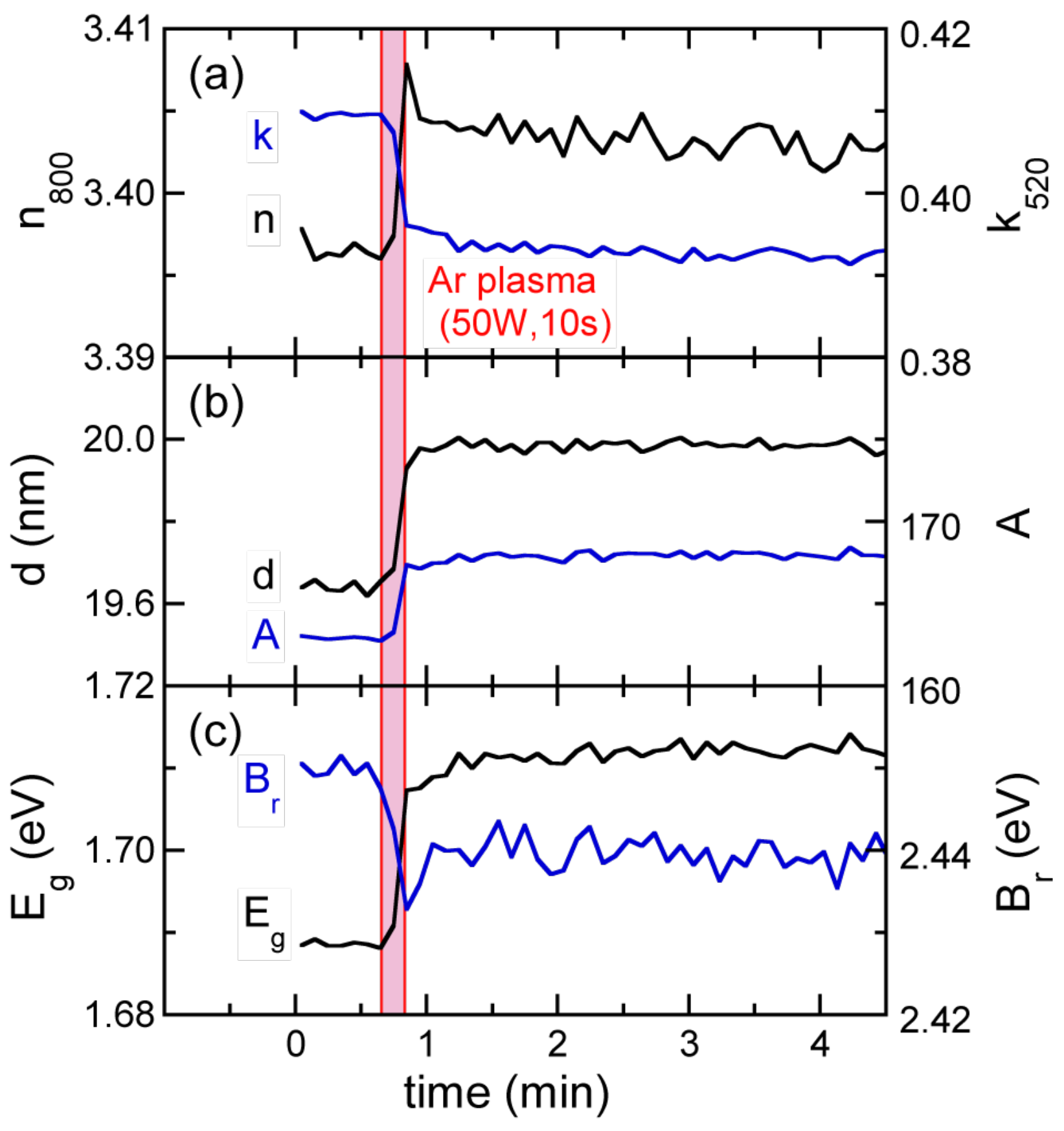
**For low-defect a-Si:H (at 180ºC)**

- The photocurrent, $I_p$, is increased after the growth of a-Si:H, denoted by 1–4. **This increase indicates a reduction of the interface defects**, i.e., the **c-Si surface passivation**.
- Ar plasma treatments are performed, denoted by 6–12.
- The recovery of $I_p$ is limited for a high-power *(P)* and long-period (*t*) treatment, denoted by 10–12, which indicates the formation of **residual defects**.

**For defect-rich a-Si:H (at 80ºC)**

- **$I_p$ is increased drastically by an Ar plasma treatment,** denoted by 7–9.
- **A large improvement of surface passivation** is confirmed.
- A further treatment under the high-*P* and long-*t* conditions causes a reduction in $I_p$ (denoted by 10–12).
- For comparison, Ar plasma treatments are replaced with H$_2$ plasma treatments. An increase in $I_p$ is not observed, and $I_p$ stays low.

### Real-time spectroscopic ellipsometry



- $n_{800\ nm}$ is increased by the Ar plasma treatment, while $k_{520\ nm}$ is decreased.
- An increase in $n_{800\ nm}$ is related to an increase in the oscillator amplitude (*A*), implying the formation of a **dense network structure**.
- *d* is increased by the treatment, indicating the **implantation of Ar ions** into an a-Si:H layer.
- The broadening factor ($B_r$), i.e. the network disorder of a-Si:H is reduced by the treatment, reflecting **the improvement of network disorder**.
- $E_g$ is increased by the treatment, suggesting **the reorganization of the bond configurations of Si-H$_x$**.

S. Nunomura et al., *Jpn. J. Appl. Phys.* **61**, 106001 (2022).

## Summary

- A beneficial effect of **Ar ion bombardments** to the **silicon surface passivation** is experimentally studied.
- The passivation improvement is observed as an increase in the photocurrent, which is obtained under certain conditions of Ar plasma treatments at low-*P* and short-*t*.
- The **mobile H** atoms are considered to play important roles in the **interface DB defect** termination, i.e., the surface passivation, where **the material densification** and the improvement of **the network disorder** are also required to reorganize the local interface structure.

## Acknowledgements

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