Evaluation of Sodium Migration in SiNx With Capacitance-Voltage Measurements

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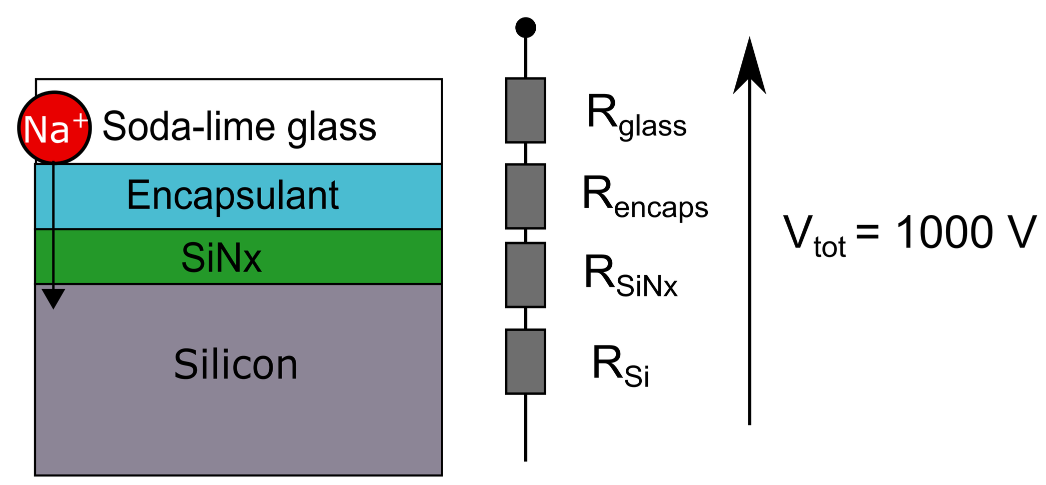
Introduction

○ Sodium is believed to be responsible for potential-induced-degradation (PID) of the shunting type [1]
○ Typical PID failure time is 7 years, but it is unclear how fast sodium diffuses through SiN_x
○ We determine sodium migration kinetics in SiN_x using the widely-spread capacitance-voltage technique
○ The potential drops across SiN_x depending on resistivity, according to the voltage divider model

Fig. 1. Sodium migration in a module and voltage divider model



○ This study focuses on high resistivity SiN_x to increase the voltage drop across SiN_x
○ SiN_x resistivity of 10^{13} Ω·cm and refractive index of 1.89

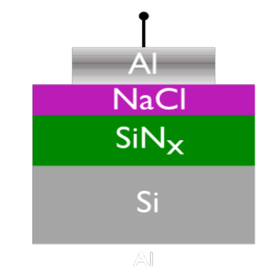
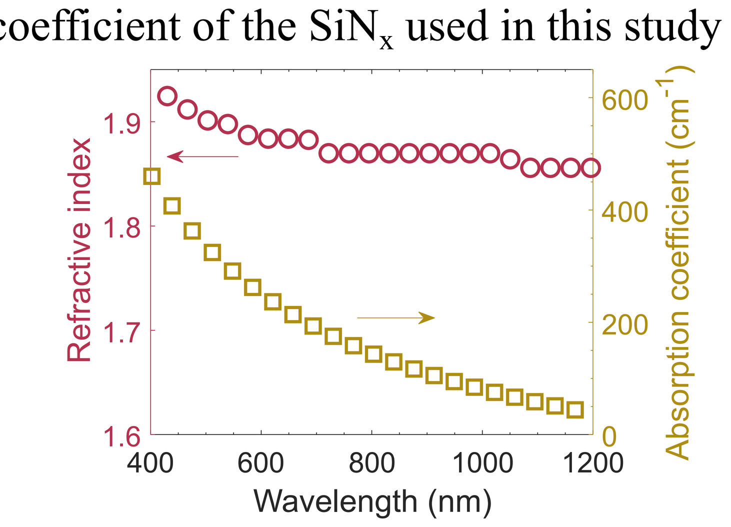


Figure 2: refractive index and extinction coefficient of the SiN_x used in this study



I. Experimental data acquisition

Fig. 3. In-situ measurements of ionic migration by capacitance-voltage

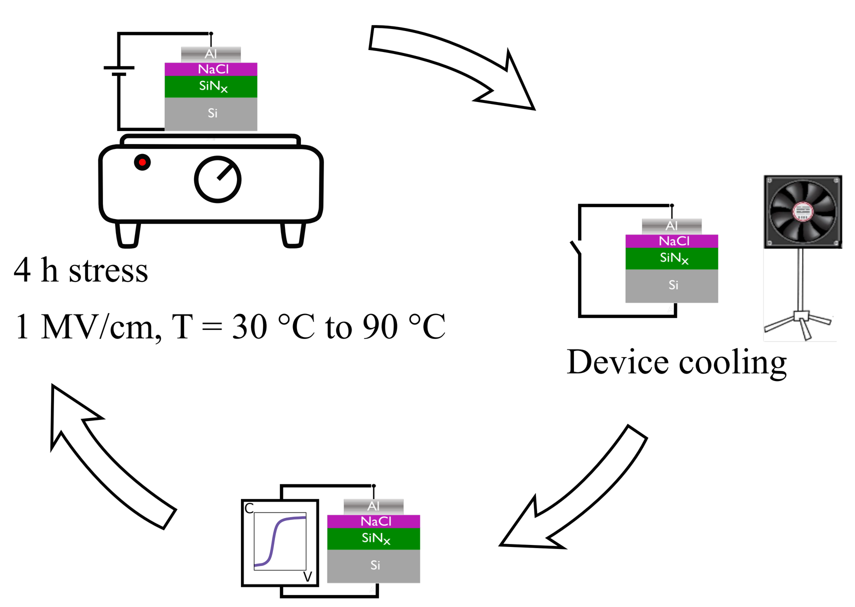
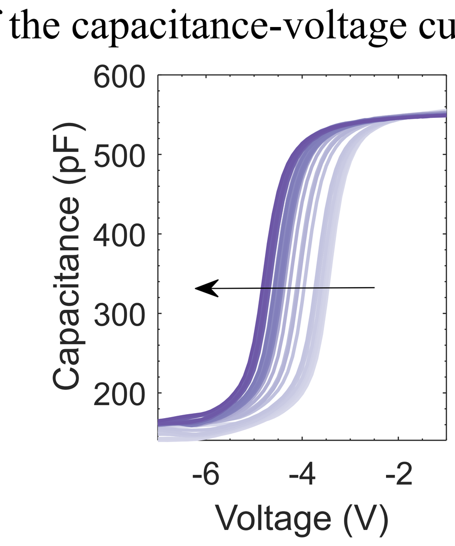
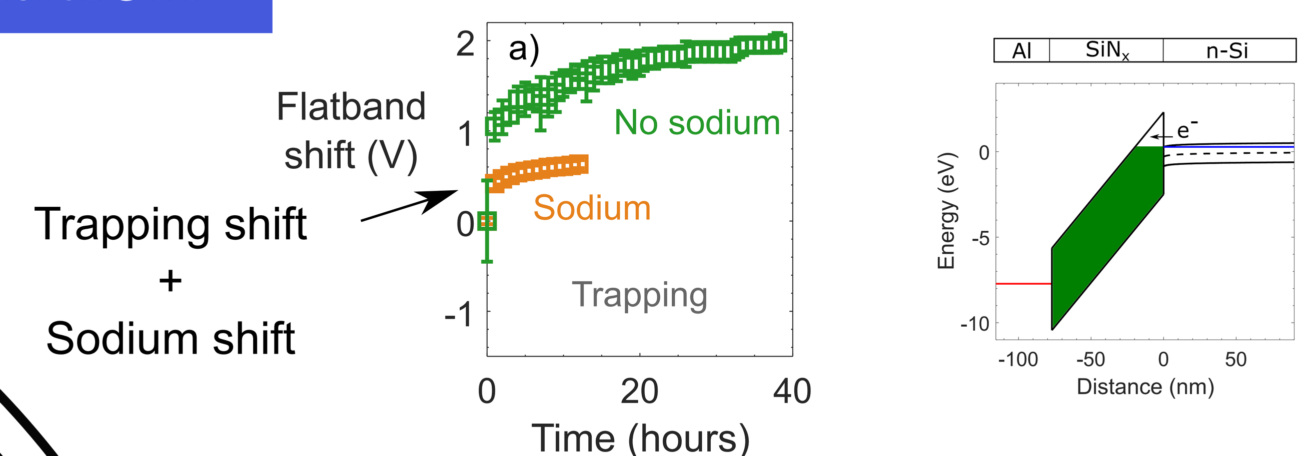


Fig. 4: Shift of the capacitance-voltage curves over time



II. Trapping estimation

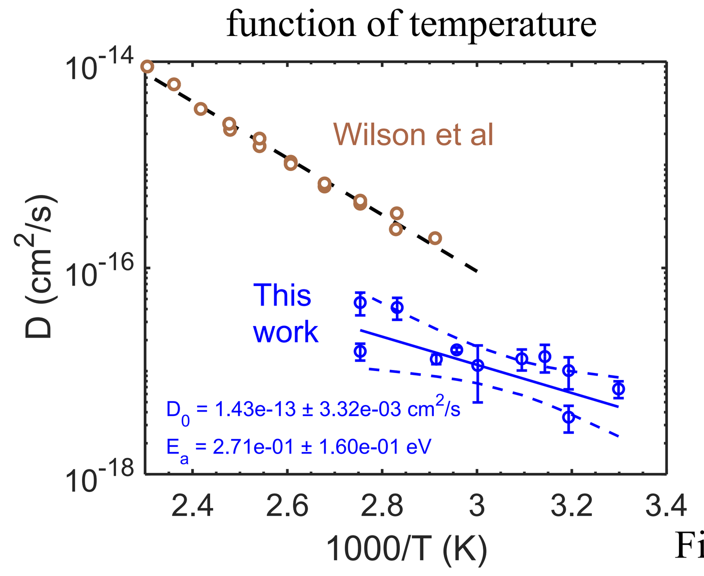
Figure 5: a) Flatband shifts measured in sodium-free and in sodium-contaminated samples with trapping b) Band diagram under a +8 V gate bias



○ Carrier traping is typical in SiN_x and strongly affects the measured flatband shift
○ Electron accumulation occurs due to the positive bias (Fig. 4).
○ The flatband shift due to trapping is obtained on sodium-free samples. It is then used as a flatband shift baseline.

V. Determination of ion migration kinetics

Figure 8: Sodium diffusivity in SiN_x as a function of temperature



○ Sodium diffusivity can be preditected based on our Arrhenius relationship
○ We estimate sodium breakthrough in SiNx after a few days only

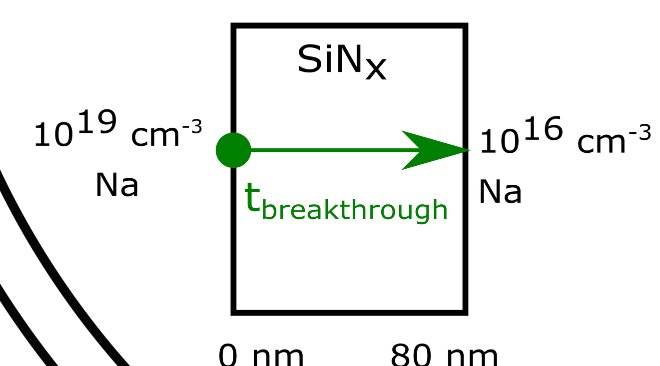
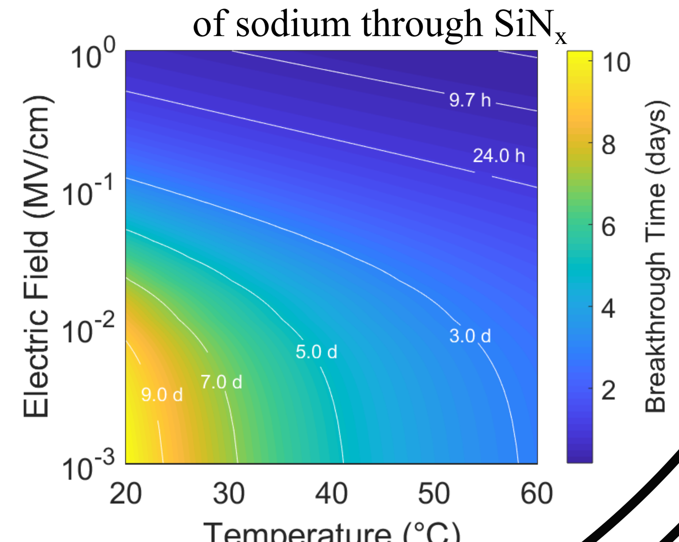
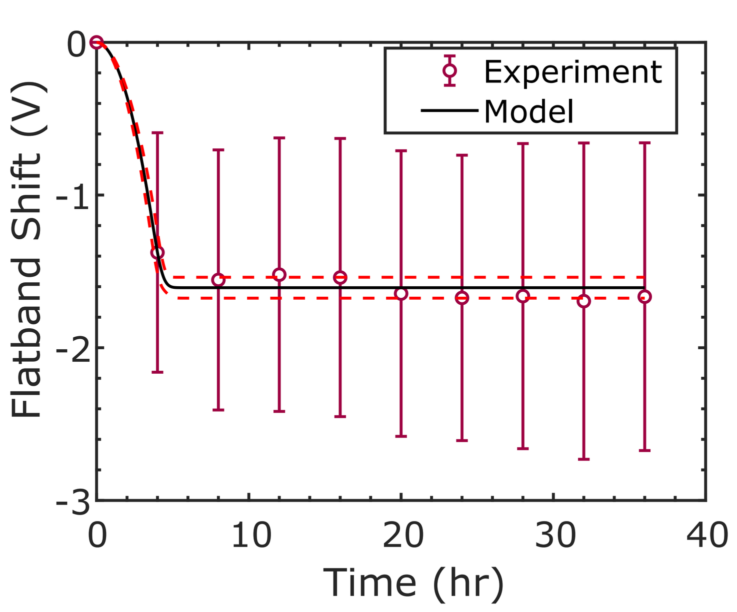


Figure 9: Simulated breakthrough time of sodium through SiN_x



IV. Flatband shift fitting

Figure 7: Fitted flatband shift as a function of time



○ Sodium concentration calculated using Nernst-Planck equation (1)
○ The integral yields the flatband shift (2)
○ The flatband shift is fitted to obtain diffusivity

Sodium concentration — Electric field — Flatband shift — Insulator thickness — Insulator capacitance

$$\frac{dC_{Na}}{dt} = \vec{\nabla} \cdot D\left(\vec{\nabla} C_{Na} - \frac{qC_{Na}}{k_B T}\vec{E}\right) \quad (1)$$

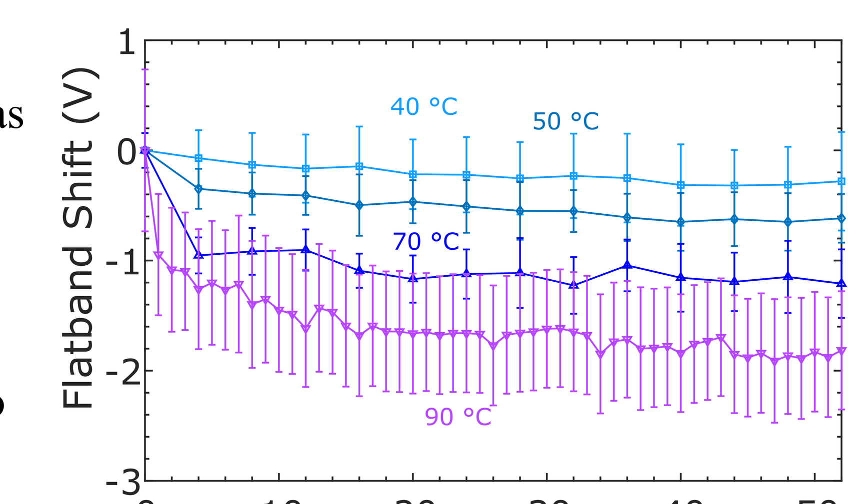
$$\Delta V_{FB} = -\frac{1}{C_{ins}} \int_0^{t_{ins}} \frac{x}{t_{ins}} C_{Na} dx \quad (2)$$

III. Flatband shift extraction

Figure 6: Extracted flatband shift caused by sodium migration

○ The total shift is obtained as $\Delta V = \Delta V_{Na\text{-}contaminated} - \Delta V_{Na\text{-}free}$ to remove the trapping contribution

○ Sodium solubility seems to increase with temperature



Summary

○ Sodium migration through SiN_X occurs within days under an electric field as low as 1 kV/cm
○ We can predict sodium migration times as a function of electric field and temperature based on our detemination of sodium kinetics
○ Other SiN_x materials with different stoechiometries (i.e. resistivities) will be studied next
○ Any other ionic species can be measured in a similar way. Further work will focus on other dielectrics (SiO_2, Al_2O_3) and other migrating ions (K^+)

References and acknowledgements

[1] V. Naumann, D. Lausch, A. Hähnel, J. Bauer, O. Breitenstein, A. Graff, M. Werner, S. Swatek, S. Großer, and J. Bagdahn, Solar Energy Materials and Solar Cells, vol. 120, pp. 383-389, 2014.
[2] M. Wilson, A. Savtchouk, P. Edelman, D. Marinskiy, and J. Lagowski, Solar Energy Materials and Solar Cells, vol. 142, pp. 102-106, 2015.

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