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Contactless and Non-destructive Determination of Dopant Profiles of Localized Boron-Diffused Regions in Silicon Wafers at Room Temperature

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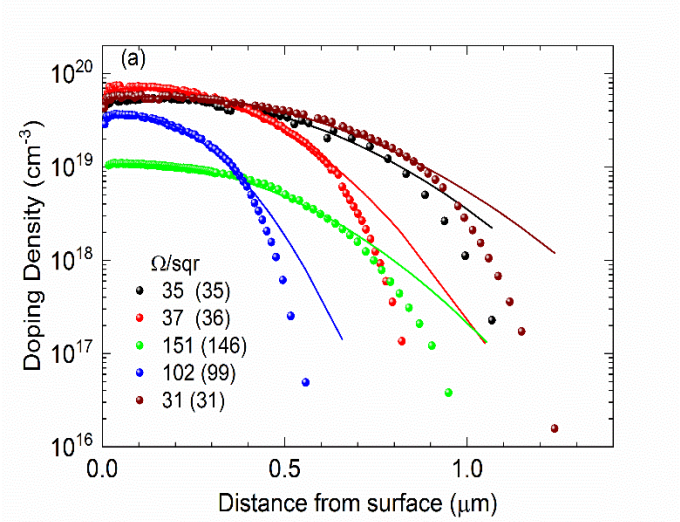
We develop a contactless and non-destructive photoluminescence (PL) based method to quickly reconstruct dopant profiles of boron-diffused regions in crystalline silicon (c-Si) solar cells at room temperature (296K) with micron-scale spatial resolution. With this newly developed technique, we can quickly detect dopant profiles by measuring PL spectra with two excitation wavelengths of 500 nm and 600 nm at room temperature. This method employs bandgap narrowing effects and various penetration depths of the two excitation wavelengths in silicon. Ultimately, we apply this technique to reconstruct the dopant profiles of the localized diffused regions (30 μm in diameter) of a passivated-emitter rear localized-diffused (PERL) solar cell precursor. The results are confirmed with a standard electrochemical capacitance-voltage (ECV) method.

Methodologies

Boron-diffused dopant profiles can be described by a Gaussian function as shown in (Eq.1).[1] The parameters include a peak dopant density (N_p), a depth factor (z_f) and a depth where the peak dopant density occurs in a sample (z_p). Fifteen boron-diffused c-Si samples whose dopant profiles have been measured by the ECV technique are used to establish correlations between dopant profiles and room-temperature PL spectra.



$$N(z) = N_p \times exp[\frac{-(z-z_p)^2}{{z_f}^2}] \qquad \text{(Eq.1)}$$

Fig. 1:

(a) ECV dopant profiles of some calibration samples and their Gaussian fittings using Eq.1. The sheet resistances calculated from these measured and fitting profiles are also shown (outside and inside the bracket, respectively).

At low temperatures ~80 K, the diffused layer and the c-Si substrate emit two PL peaks with an excitation wavelength of 500 nm. However, these two peaks are indistinguishable at room temperature because of thermal broadening effects. Thus, we introduce a PL ratio as a metric to analyze the dopant profiles. It is calculated as the ratio of the integrated PL intensities between 1135 nm–1250 nm (diffused layer) and 1115 nm–1135 nm (silicon substrate). Our previous research has proved that photon reabsorption, sample surface geometry and thickness do not impact the PL ratio[2]. In addition, changing excitation wavelengths can lead to varying PL ratios due to different penetration depths achieved by different laser wavelengths. The larger the excitation wavelength is, the more PL signal is captured from the silicon substrate, and hence less signal from the diffused layer. We also employ this relative change in PL ratios with different excitation wavelengths to analyze dopant profiles at room temperature.

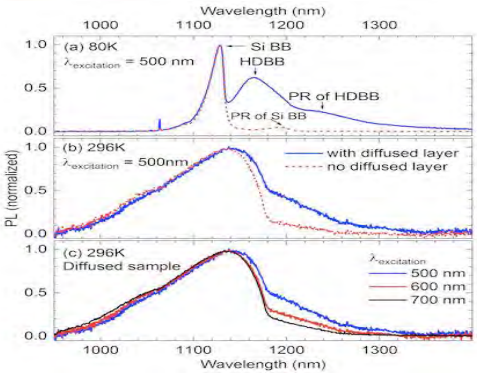


Fig. 2 (a) (b):
Comparison of normalized PL spectra from c-Si samples with and without a diffused layer captured with the 500-nm excitation wavelength at
(a) 80 K (two peaks if there is a diffused layer) and
(b) 296 K (only one peak even though the diffused layer exists)

Fig. 2 (c):
PL spectra from the diffused wafer with various excitation wavelengths at 296 K.

Results

We establish three correlation equations between z_p, z_f, N_p of dopant profiles and the PL ratios defined above. These equations reveal that we can solve z_p, z_f, N_p of the dopant profiles of localized boron-diffused regions of c-Si, based on PL spectra captured with 500 nm and 600 nm excitation wavelengths at room temperature.

$$z_p = 0.403 z_f - 0.029 \quad \text{(Eq.2)}$$

$$PL\ Ratio_{500nm} = 0.339X^2 - 9.54X + 69.23 \quad \text{(Eq.3)} \qquad \text{where } X = log_{10}[N_p(z_p + z_f)]$$

$$\frac{PL\ Ratio_{500nm} - PL\ Ratio_{600nm}}{PL\ Ratio_{500nm}} = -0.064\ln(z_f) + 0.041 \quad \text{(Eq.4)}$$

We apply this room-temperature PL-based method to reconstruct dopant profiles of a large-area diffused region (1 cm × 1 cm, Fig. 3 (a)) and localized-diffused regions of a PERL solar cell precursor (Fig. 3 (b) and 3 (c)). In Fig. 3 (b) and 3 (c), the maps of z_f and N_p are extracted from micro-PL maps performed with 500-nm and 600-nm excitation wavelengths. For both cases, the reconstructed dopant profiles agree with ECV measurements, suggesting that we can utilize the newly developed technique to perform fast, contactless and non-destructive determinations of dopant profiles of localized boron-diffused regions of c-Si wafers.

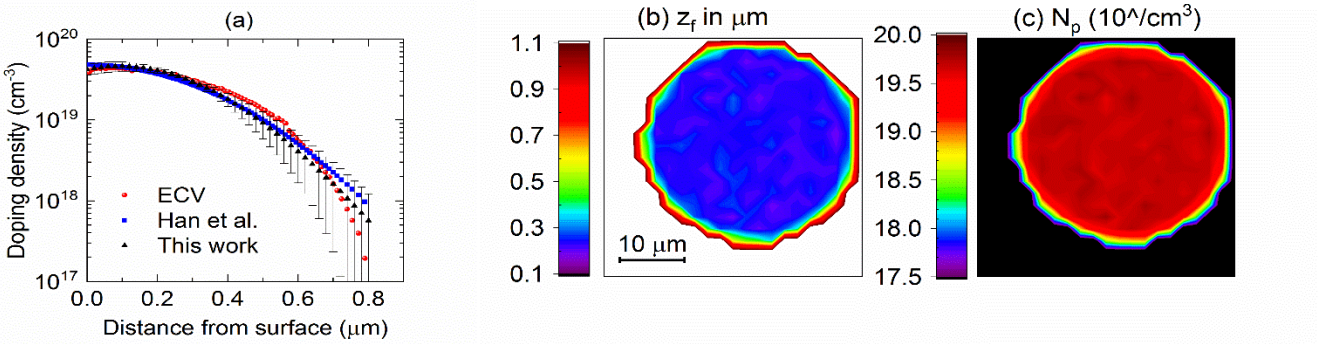


Fig. 3: (a) Comparison of dopant profiles among ECV measurements (red circles), Han *et al.*'s method at 80 K[1] (blue squares), and this work at room temperature (black triangles). The error bar is ± one standard deviation, obtained from fifteen data points in the 1 cm × 1 cm diffused area of the patterned wafer. (b) z_f and (c) N_p maps of a localized boron-diffused region in the PERL solar cell precursor.

The final presentation will provide an in-depth underlying physics of this technique and demonstrate a wide range of applications in c-Si photovoltaics. This contactless and non-destructive PL-based technique could be a powerful tool to characterize localized boron-diffused regions for c-Si solar cells.

References

[1] Y.-J. Han, E. Franklin, D. Macdonald, H. T. Nguyen, D. Yan, IEEE Journal of Photovoltaics, vol. 7, pp. 1693-1700, 2017.

[2] H. T. Nguyen, S. Johnston, A. Paduthol, S. P. Harvey, S. P. Phang, C. Samundsett, C. Sun, Di Yan, T. Trupke, M. M. Al-Jassim, D. Macdonald, Sol. RRL, vol. 1, p. 1700088, 2017.