Optical Properties and Fano Resonance Behavior in Silicon Nanowires with *p-n* Junctions: Mapping the Junction

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Materiales Semiconductores y nanoestructuras para la Optoelectrónica

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ABSTRACT

Silicon nanowires (NWs) with axial homojunctions have exhibited superior forward current density compared to traditional bulk silicon *p-n* junctions, making them highly promising for photovoltaic applications with minimal absorption losses. In particular, understanding the intricate interplay between dopants and these structures is crucial for enhancing the NW properties. Contactless optical techniques are suitable for NW characterization, in particular micro-Raman spectroscopy permits the analysis of axial *p-n* junctions in Si NWs using the Fano asymmetry parameter (q). The micro-Raman scan along the NW allows us to distinguish the *n*-type segment, the charge-depleted region at the *p-n* junction, and the *p*-type segment. Micro-Raman spectroscopy allows contactless estimation of the free carrier concentration, together with structural characterization, and the junction characteristics.

MOTIVATION

Photovoltaic devices:

- **Homojunctions**
- **Doping**
- **Defects**

Raman spectroscopy

Essential features accessible:

- ✓ **Doping level**
- ✓ **Junction characteristics**

RESULTS

Doping calibration by Fano resonance in Si wafers

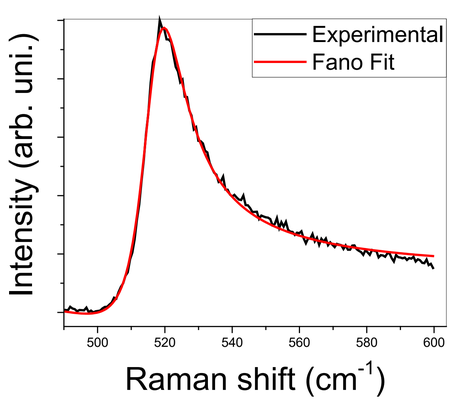


Fig.1: Characteristic Raman spectra of *p*-type doped silicon showing Fano resonance

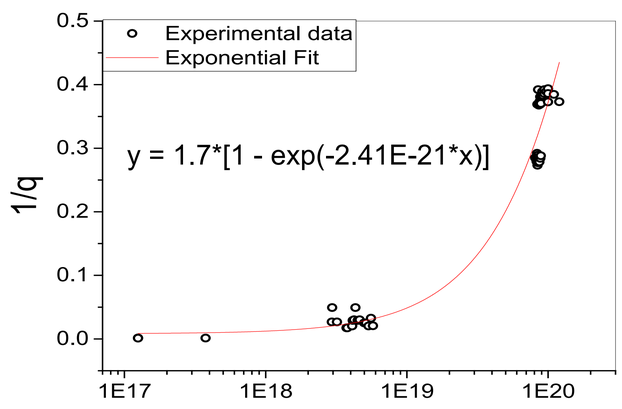


Fig.2: Correlation between doping levels and coupling strength (1/q) derived from Fano fitting of Raman spectra in three *p*-type doped Si wafers.

Fano Equation [1-3]

$$I(\omega) = A\frac{(q+\varepsilon)^2}{(1+\varepsilon^2)} \qquad \varepsilon \equiv \frac{\omega-\omega_0}{\Gamma}$$

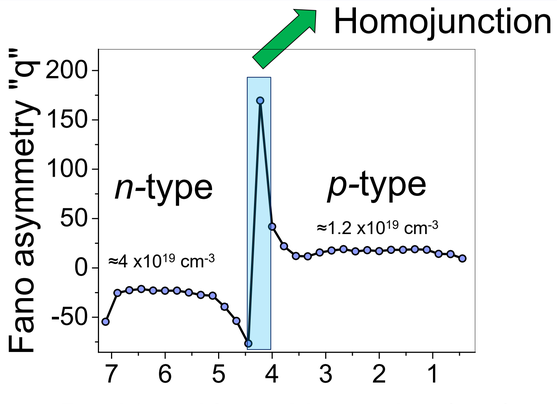


Fig.3: Asymmetry parameter *q* from Fano fitting on a linescan along a single Si NW with a *p-n* junction

Raman linescan allows us to diferenciate between *p*- and *n*-type region, and the depletion zone (Lorentzian behavior |q|>100)

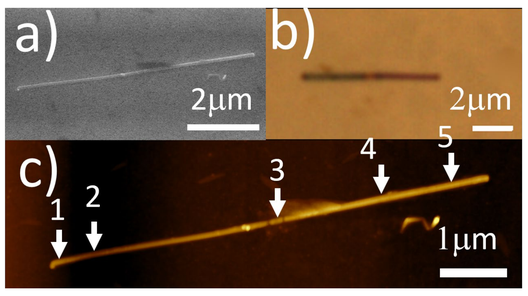
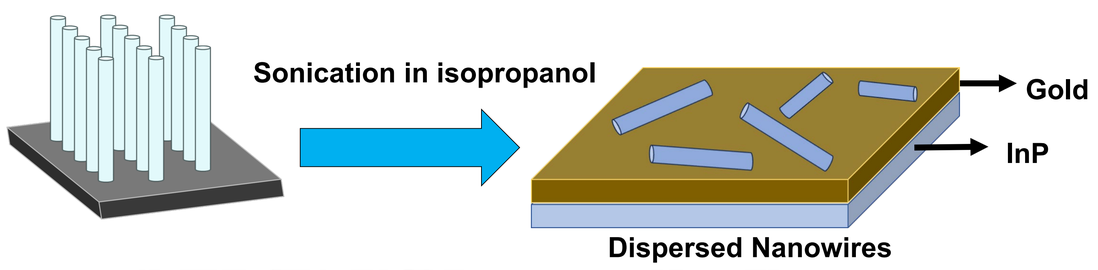


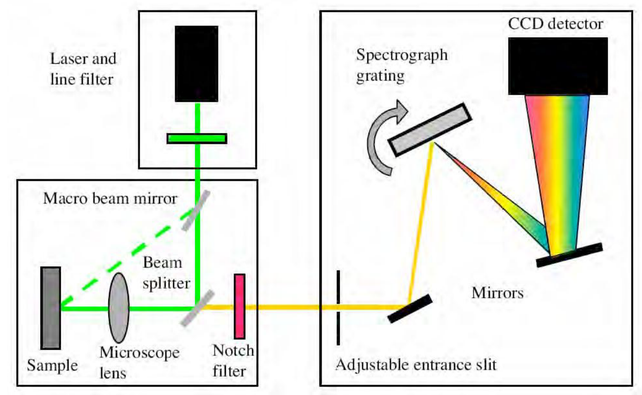
Fig. 4: a) SEM image of a Si NW with *p-n* junction showing gradual changes in brightness, b) optical image of the same NW oriented perpendicular to the laser polarization, and c) AFM image revealing bending in the *n*-type region and variations in diameter

Table 1: Si NW diameter values at several points displayed in Fig. 1.

Spot	1	2	3	4	5
Diameter (nm)	92	81	93	100	104

EXPERIMENTAL

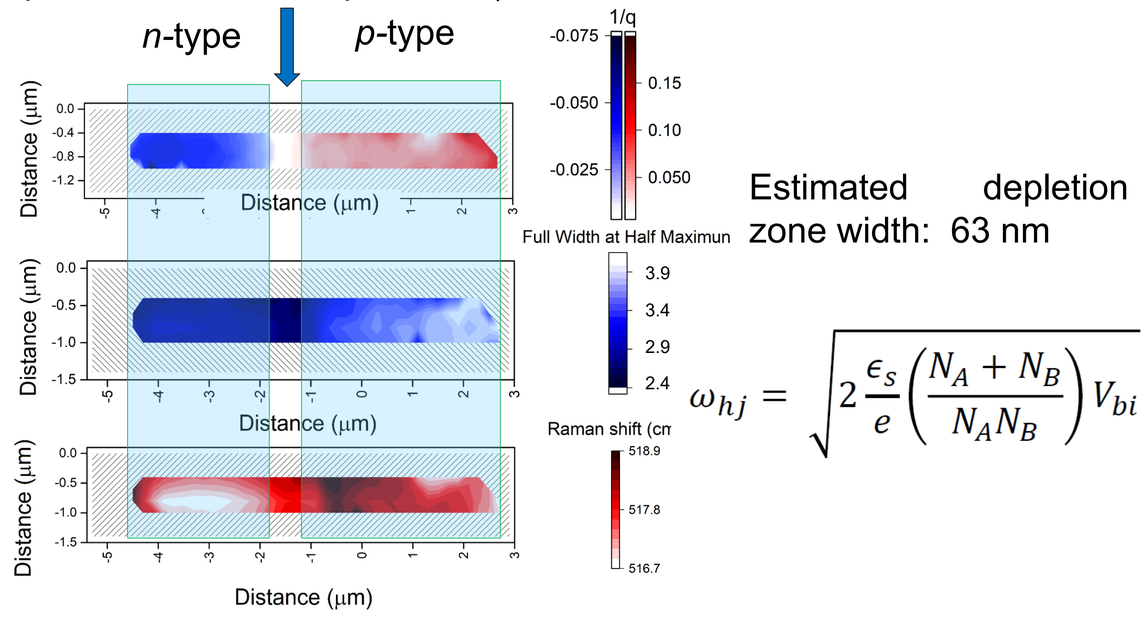




Raman configuration

ANALYSIS

Depletion zone: laser spot = 0.8 μm



Estimated depletion zone width: 63 nm

$$\omega_{hj} = \sqrt{2\frac{\epsilon_s}{e}\left(\frac{N_A+N_B}{N_A N_B}\right)V_{bi}}$$

Fig . 5: Map representation of Si NW showing the fitting parameters: 1/q (coupling strength), Full Width at Half Maximun (FWHM), and Frequency.|

- ➢ The coupling strength (1/q) factor decreased in the the carrier depletion zone (Lorentzian lineshape).
- ➢ The white region in the lower panel indicates strain due to bending at the *n*-type region.

CONCLUSIONS

- Calibration curve of coupling strength vs free carrier concentration fits an exponential law.
- Linescan reveals homojunction.
- Morphology images showed small diameter variations along the NW.
- Micro-Raman mapping of the NWs allowed us to access the width of the free carrier concentration of the *p* and *n* segments, and also allowed to assess the carrier depletion zone at the homojunction.

REFERENCES

[1] Fano U. (1961). *Effects of configuration interaction on intensities and phase shifts*. **Phys. Rev. 124, 1866.**

[2] Cerdeira, F., Fjeldly, T. A., & Cardona, M. (1973). *Effect of free carriers on zone-center vibrational modes in heavily doped p-type Si. II. Optical modes*. ***Physical Review B*, *8*(10), 4734.**

[3] Burke, B. G., Chan, J., Williams, K. A., Wu, Z., Puretzky, A. A., & Geohegan, D. B. (2010). *Raman study of Fano interference in p-type doped silicon*. ***Journal of Raman Spectroscopy*, *41*(12), 1759-1764.**

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