# Strain Measurement Using Nanobeam Diffraction Coupled with Precession


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## Introduction

- Measurement of strain with high spatial resolution and high precision in semiconductor devices is critical to monitor the designed and unintended strain distributions.
- Use of spot diffraction patterns with nanobeam illumination gives higher spatial resolution than other TEM techniques[1].
  - – Experiment is relatively simple.
- Technique is made possible by beam precession
  - –Improves quality of diffraction patterns..


[1] D Cooper *et al.*, Journal of Physics: Conference Series **326** 012025 (2011).


## Limitations of Existing TEM Strain Measurement Methods

| Technique | Advantages | Limitations |
|---|---|---|
| Convergent beam electron diffraction | High spatial, strain sensitivity | • Needs the sample to be relatively thick (>150 nm) • Sample needs to be oriented away from a low index axis. • Very sensitive to strain relaxation |
| Dark field holography | High spatial resolution (5 nm), large field of view (1 µm×1 µm) | • Requires unstrained reference with identical crystallographic orientation area close to strained region |
| High resolution imaging | High spatial resolution (< 1 nm) | • Limited field of view (100 nm$^2$ × 100 nm$^2$) • Stringent requirements on specimen quality |

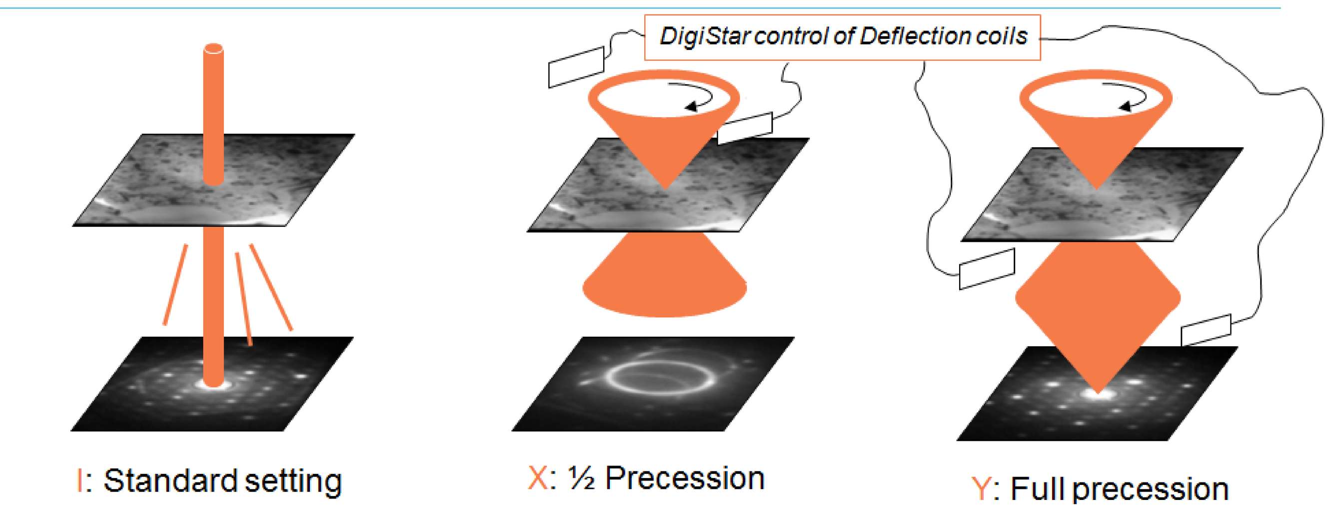
## Conventional Nanobeam Diffraction

- Acquire spot diffraction patterns from strained and unstrained regions using a quasi-parallel nanoprobe (<5 nm)
- Use measured shift in spot positions to calculate strain
- Experiment is relatively straightforward

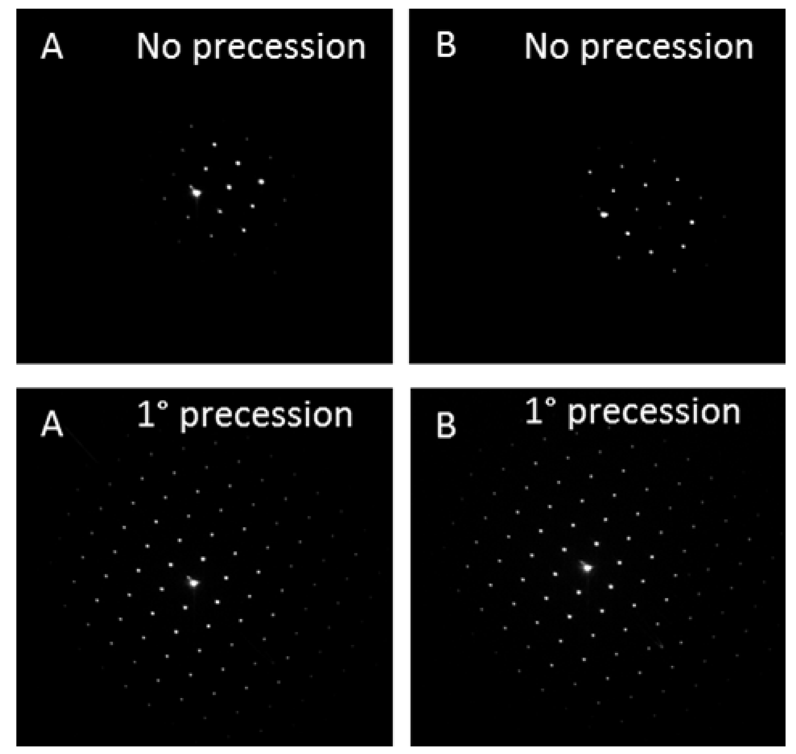
**Limitations**

- Presence of strong dynamical effects lead to rapid changes in spot intensities with small thickness and orientation changes
- Strong dependence of spot intensities on changes in local thickness and orientation makes automated analysis challenging
  - – Requires manual intervention in identifying spot positions
- Inadequate sampling of higher order reflections limits the accuracy

## Precession Electron Diffraction




Portillo, J., et al. (2010). *Materials Science Forum* **23**, 1-7

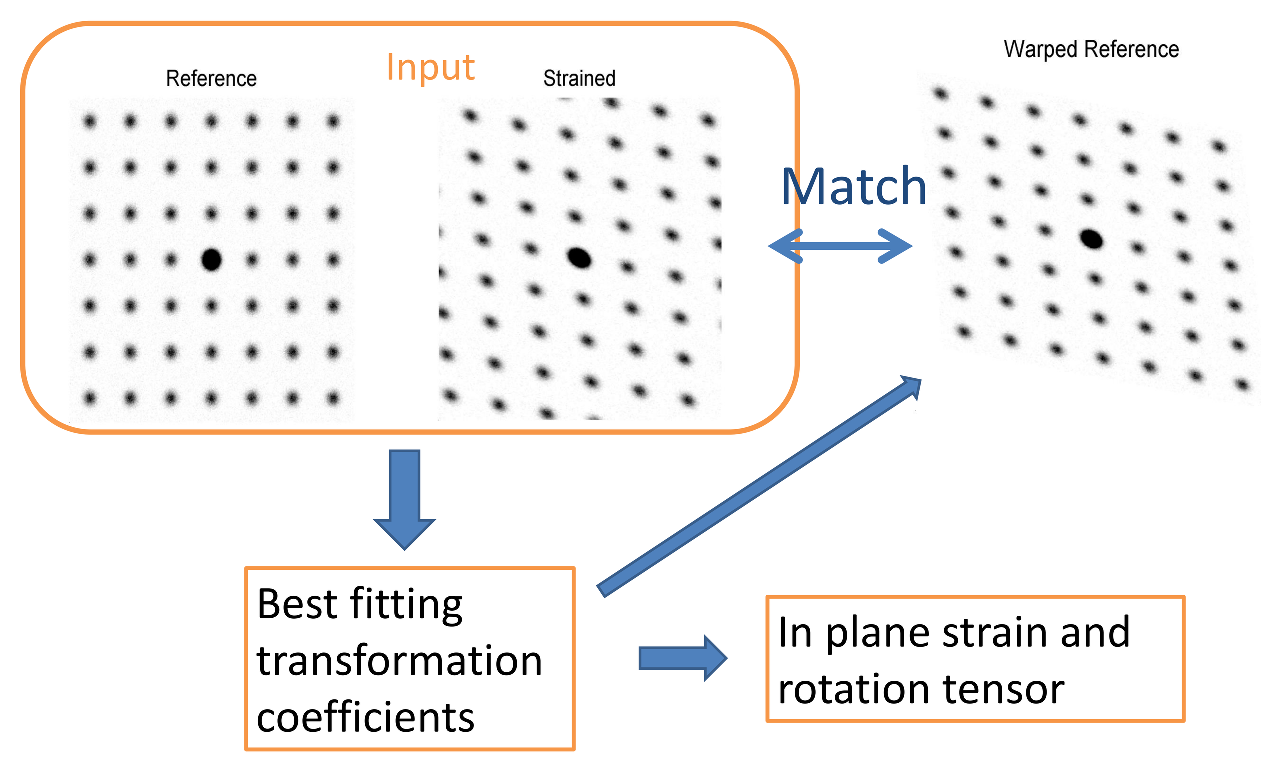



Diffraction patterns from two points 120 nm apart from Si/SiGe multilayered specimen

- No particular beam is strongly diffracted – reducing strong dynamical effects
- Insensitive to small thickness and orientation changes
- Number of spots increases – better sampling of higher order spots

## Strain Measurement Analysis

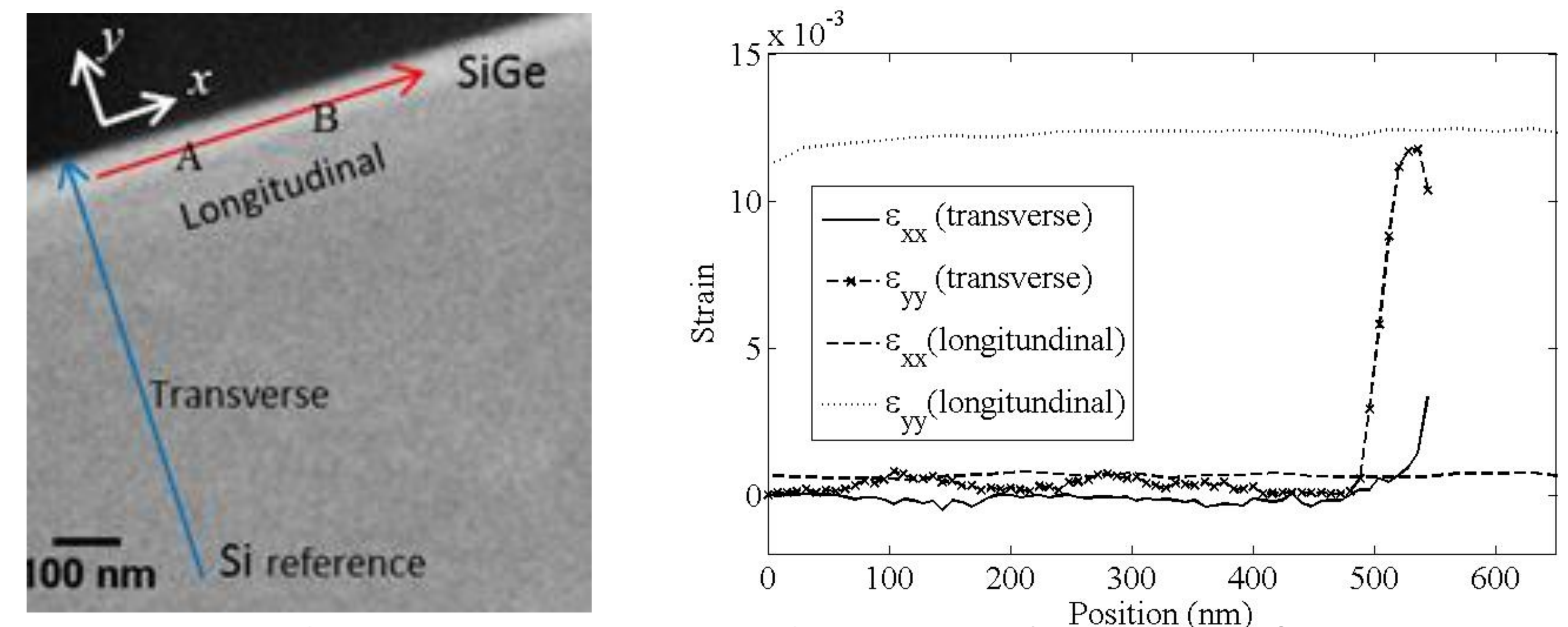
- Diffraction patterns from strained region are matched against a reference pattern.
- Reference pattern from unstrained region.
- Correlation distance used as the metric for fitting reference to strained patterns.
- Results include strain in $x$ and $y$-directions and shear (not shown).
  - – Relative to x-direction specified by user.




## Results

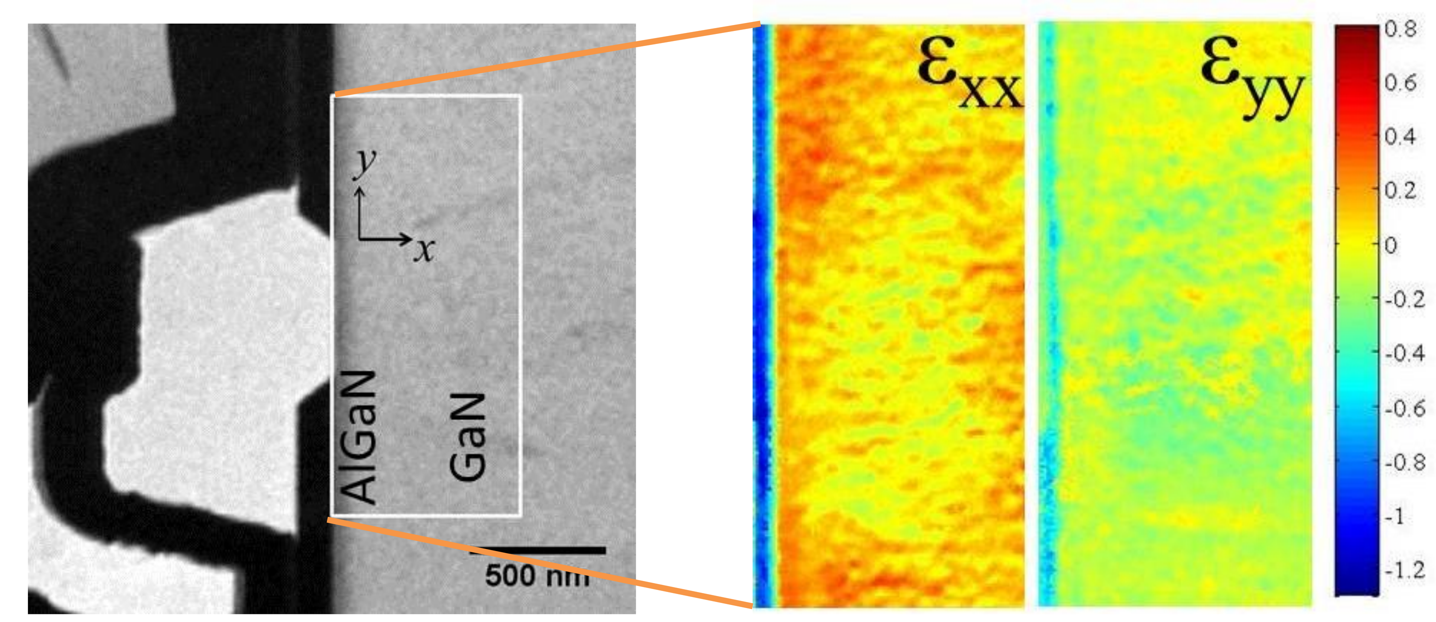
- Data acquired with Zeiss Libra L200 TEM.
  - – Field Emission Gun (FEG)
  - – Scanning TEM (STEM) mode.
  - – NanoMEGAS DigiSTAR unit for precession and descanning of beam.
- Positive percentage strain values correspond to tensile strain, negative values compressive.
- Precision of strain measurement is 0.02% in profile below.
  - – Precision can depend on characteristics of data, such as resolution of spot patterns.

1. Strain profile of an Si/SiGe layer.



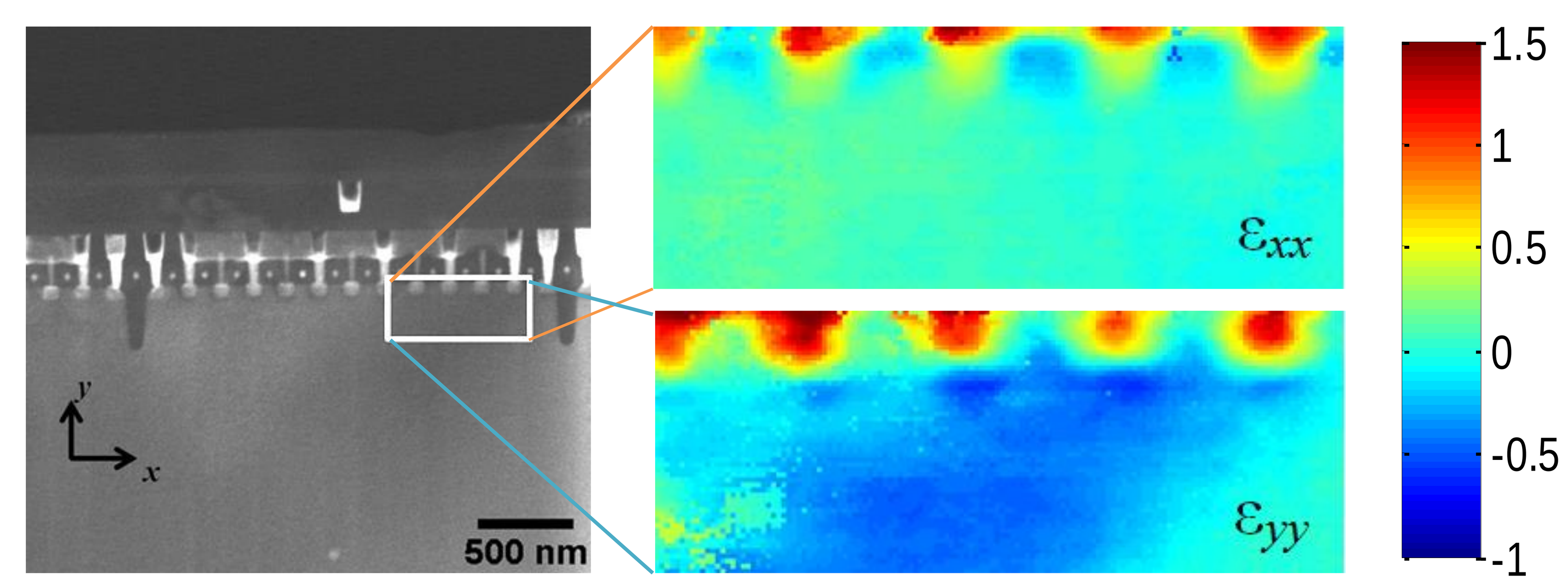

- Strain in $x$-direction is near zero, indicating a coherent interface.

2. Strain maps from a AlGaN/GaN HEMT. (provided by Cree)




- For such devices, tensile strain is expected to be asymmetric on different sides of the gate, and this is seen here.
- Compressive strain perpendicular to the interface ($x$-direction ) of ~1% is seen in the AlGaN region.

3. Strain maps from the Si region of a pMOS device.




- $x$ and $y$-directions aligned with [220] and [002] directions in Si.
- Localized biaxial tensile strain close to contact edges.