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

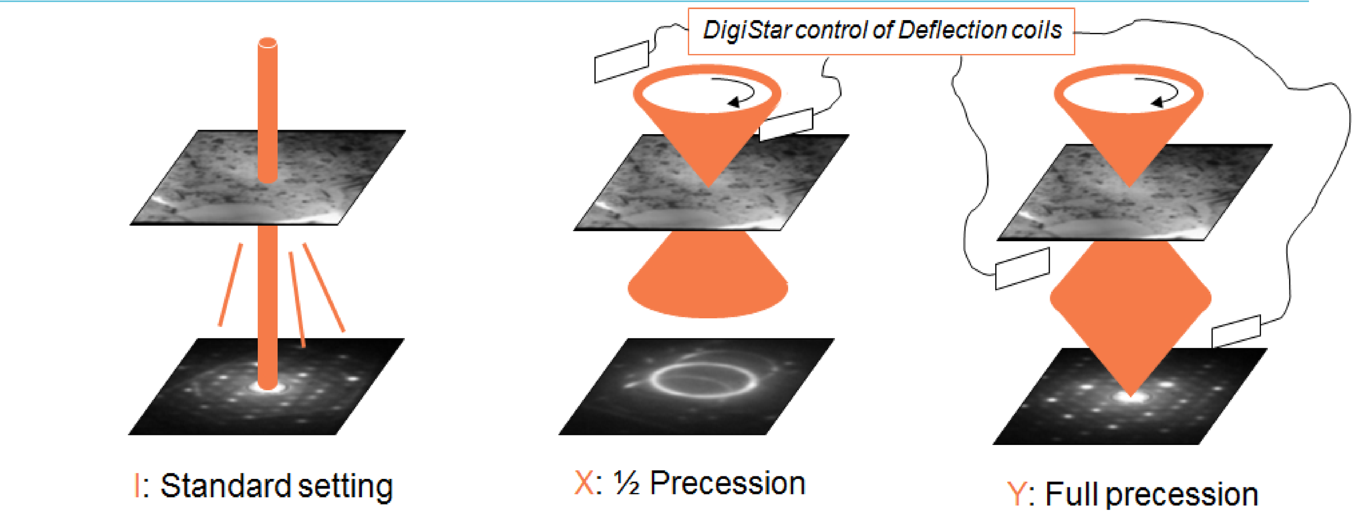
Conventional Nanobeam Diffraction

- 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

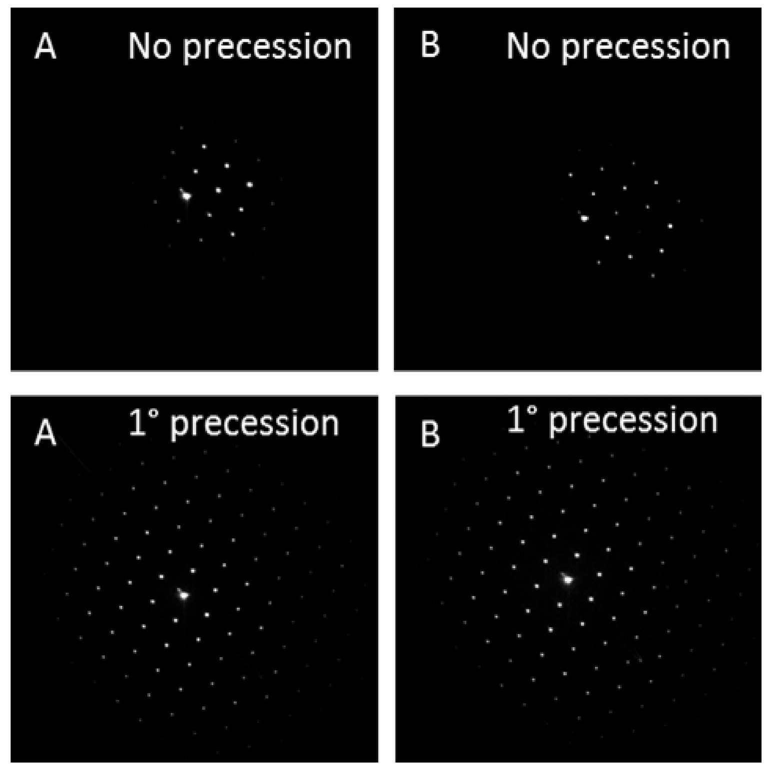
Limitations

- 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

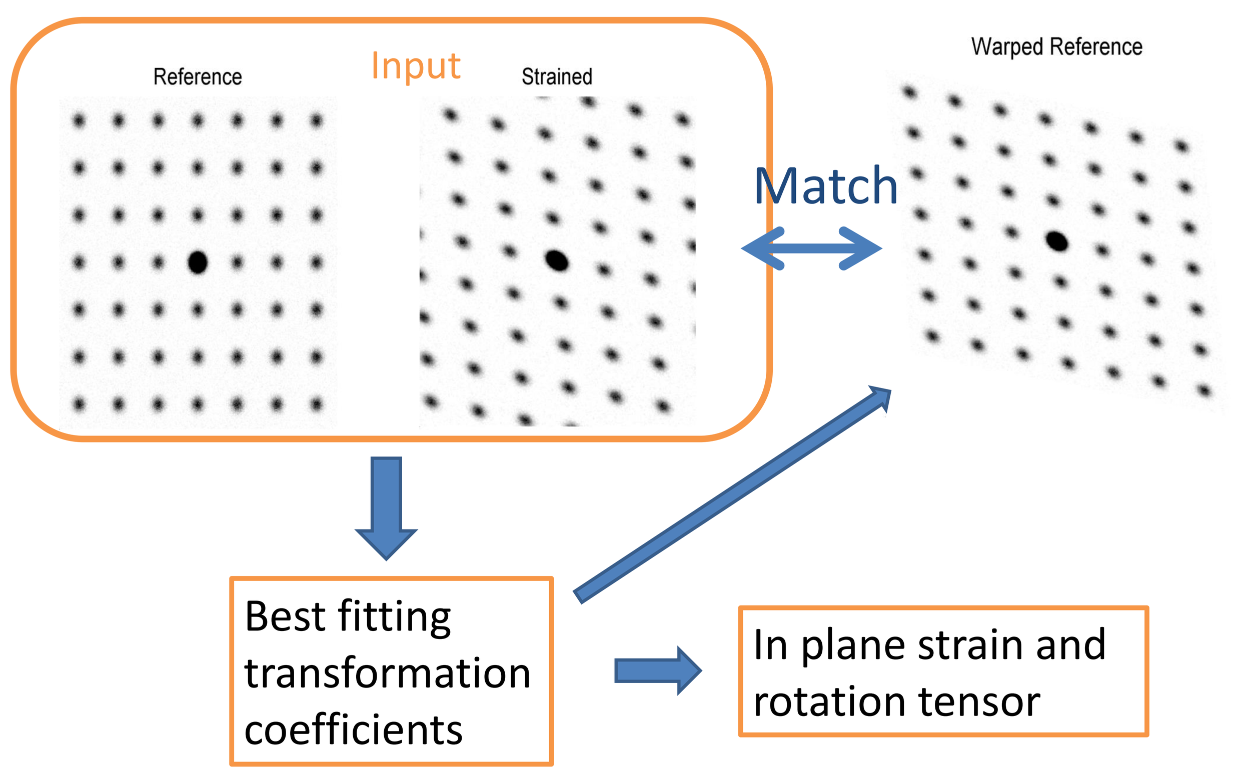


Diffraction patterns from two points 120 nm apart from Si/SiGe multilayered specimen

- 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

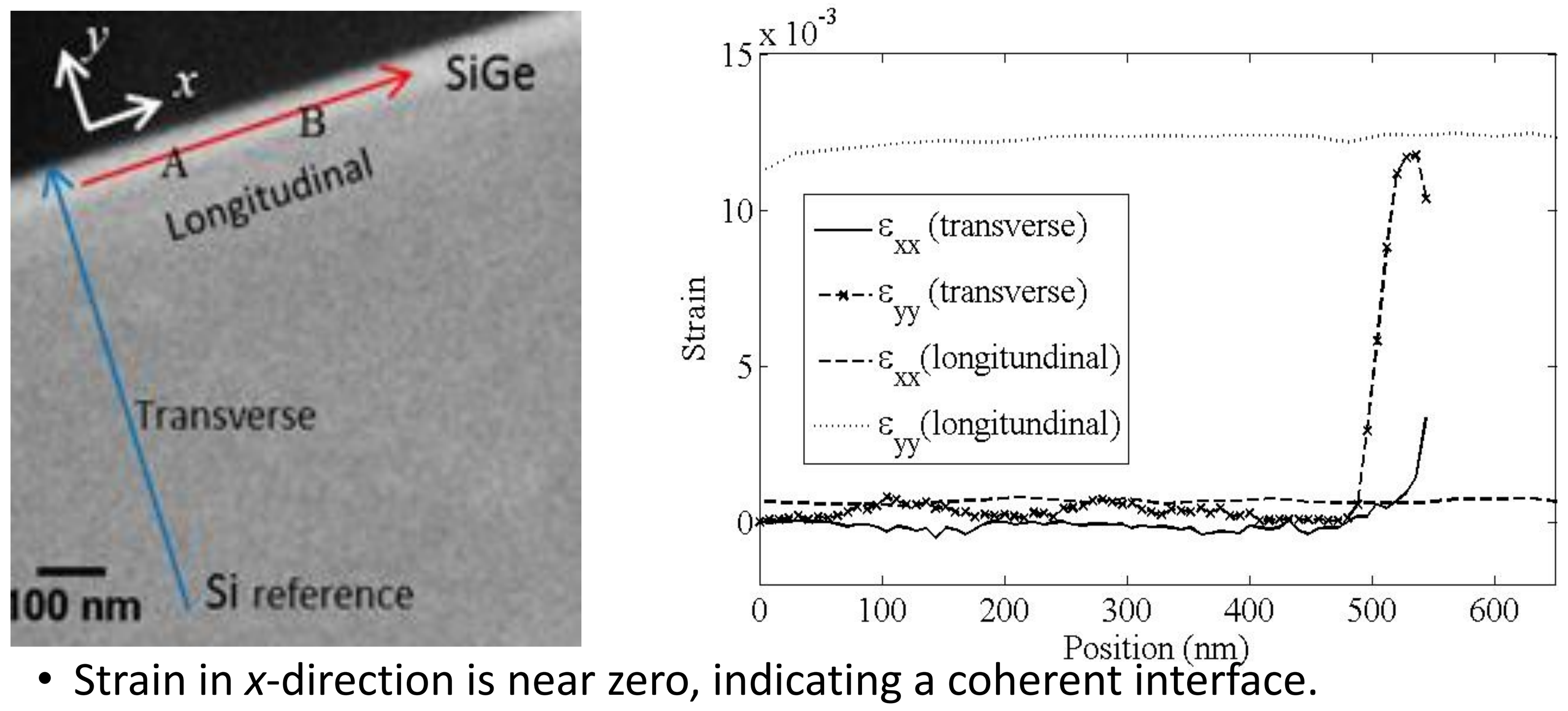
- Diffraction patterns from strained region are matched against a reference pattern.
- Reference pattern from unstrained region.
- Correlation distance used as the metric for fitting reference to strained patterns.
- Results include strain in *x* and *y*-directions and shear (not shown).
  - Relative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



Results

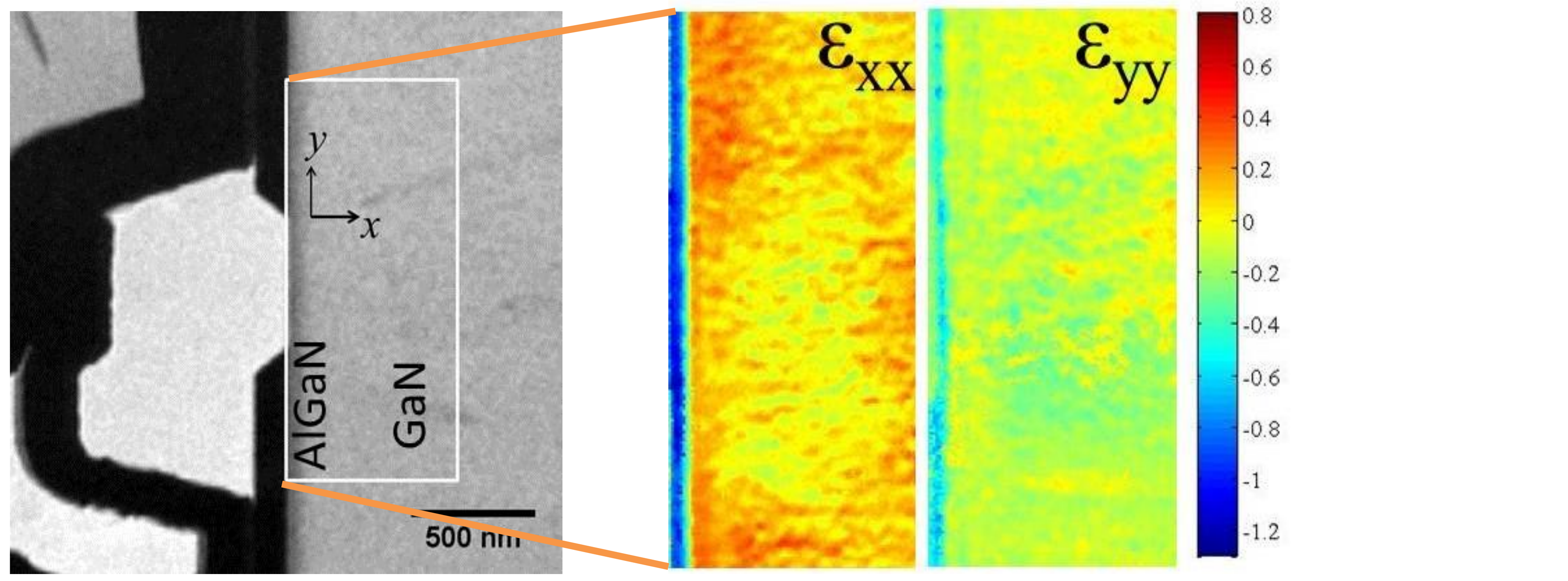
- Data acquired with Zeiss Libra L200 TEM.
  - Field Emission Gun (FEG)
  - Scanning TEM (STEM) mode.
  - NanoMEGAS DigiSTAR unit for precession and descanning of beam.
- Positive percentage strain values correspond to tensile strain, negative values compressive.
- Precision of strain measurement is 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.



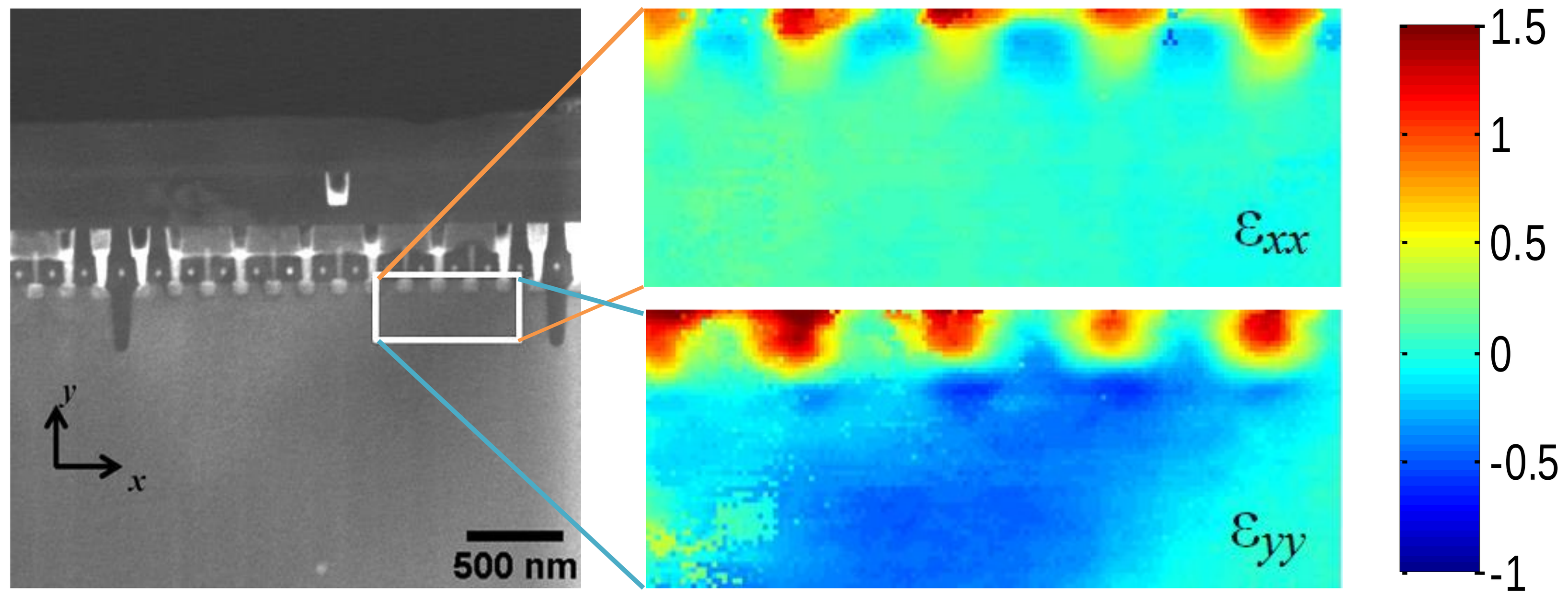
- Strain in *x*-direction is near zero, indicating a coherent interface.

2. Strain maps from a AlGaN/GaN HEMT



- 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.