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[3].
- Technique is made possible by beam precession.

RESULTS

- Data acquired with Zeiss Libra L200 TEM.
  - Field Emission Gun (FEG)
  - Scanning TEM (STEM) mode.
- Positive percentage strain values correspond to tensile strain, negative values compressive.
- Precision of strain measurement is 0.02% in profile below.

LIMITATIONS OF EXISTING TEM STRAIN MEASUREMENT METHODS

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>Convergent beam electron</td>
<td>High spatial, strain sensitivity</td>
<td>• Needs the sample to be relatively thick (&gt;150 nm)</td>
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<tr>
<td>Dark field holography</td>
<td>High spatial resolution (5 nm), large</td>
<td>• Requires unstrained reference with identical</td>
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<td></td>
<td>field of view (1 (\mu)m x 1 (\mu)m)</td>
<td>crystallographic orientation area close to</td>
</tr>
<tr>
<td>High resolution imaging</td>
<td>High spatial resolution (&lt; 1 nm)</td>
<td>• Limited field of view (100 nm(^2) x 100 nm(^2))</td>
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<td>• Stringent requirements on specimen quality</td>
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CONVENTIONAL NANOBEBEAM 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

- 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

DIFFRACTION PATTERNS FROM TWO POINTS 120 NM APART FROM Si/SiGe multilayered specimen

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.

\[ e_{xx} \] \(\text{in plane strain and rotation tensor} \]

\[ e_{yy} \] \(\text{Match} \]

\[ e_{xx} \] \(\text{Input} \]

\[ e_{yy} \] \(\text{Reference} \]

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.

\[ e_{xx} \]

1. Strain profile of an Si/SiGe layer.

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.

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\[ e_{yy} \]