Motivation and Goals
The ability to characterize and control the surface morphology of thin dielectric and semiconductor substrates is essential in semiconductor industry. In particular, high quality films of Al₂O₃ on Si substrate and beryllium-doped InGaAs alloys on InP are of interest as a potential high-K dielectric material in the metal-oxide-semiconductor field-effect transistor, and a P-type high carrier mobility channel layer. The goal of the present study is to apply computational image processing techniques to identify the surface texture parameters that distinguish the deposited films from the control sample, such as the bare substrate (Si or InP).

Surface characterization is performed by atomic force microscopy (AFM), and image analysis includes computation of the first order histogram statistics with the built-in ImageJ Batch Texture plug-in. (3) Harlak, Broadbridge, DaPonte, Gherasimova, Proc. of SPIE, vol. 7538, p.75380E-1, 2010.

Samples and AFM Results

### Al₂O₃ / Si synthesized by Jet Vapor Deposition (JVD)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Carrier gas</th>
<th>Deposition pressure (sccm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃_1</td>
<td>Ar + N₂</td>
<td>400</td>
</tr>
<tr>
<td>Al₂O₃_2</td>
<td>Ar + N₂</td>
<td>300</td>
</tr>
<tr>
<td>Al₂O₃_3</td>
<td>Ar</td>
<td>400</td>
</tr>
</tbody>
</table>

Material synthesis: T. P. Ma, Yale University

### InGaAs:Be / InP synthesized by Molecular Beam Epitaxy (MBE)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Be cell temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>InGaAs_1</td>
<td>820</td>
</tr>
<tr>
<td>InGaAs_2</td>
<td>840</td>
</tr>
<tr>
<td>InGaAs_3</td>
<td>880</td>
</tr>
</tbody>
</table>

Material synthesis: M. L. Lee, Yale University

1x1 µm² AFM scans of the Al₂O₃ series

- Control (Sb)
- Vertical scale: 0 - 15 nm

4x4 µm² AFM scans of the InGaAs series

- Control InGaAs_1
- InGaAs_2
- InGaAs_3
- InGaAs_4
- Vertical scale: 0 - 65 nm

Statistical Data Collection

Raw image transformation for Image analysis

- Raw AFM Image
- Flattened AFM Image
- Crop and Grayscale Image
- Processed Image

Image processing flow chart

Data obtained directly from AFM:
- RMS roughness
- Mean roughness
- Skewness
- Kurtosis

Seven parameters that exhibit the greatest difference between the thin film samples and the control are selected based on a t-test with unequal variance:
- Contrast
- Angular second moment
- Inverse difference moment
- Entropy

= Haralick statistics (2nd order Haralick statistics)

### Statistical Data Analysis

#### Seven parameters selected based on a t-test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>p-value*</th>
<th>Mean Roughness</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃_1</td>
<td>7.39E-03</td>
<td>5.34E-03</td>
<td>7.65E-03</td>
</tr>
<tr>
<td>Al₂O₃_2</td>
<td>7.49E-03</td>
<td>5.34E-03</td>
<td>7.65E-03</td>
</tr>
<tr>
<td>Al₂O₃_3</td>
<td>1.54E-02</td>
<td>7.16E-03</td>
<td>5.34E-03</td>
</tr>
</tbody>
</table>

#### Parameters exhibiting the lowest p-value in each group:
- Mean roughness, Zero inverse difference moment, Zero entropy.

= based on the null hypothesis that the parameters show no significant difference with the control, p-value represents the probability of obtaining a result at least as extreme as the experiment.

#### Parameter Correlation

3D scatter plot: X - mean roughness; Y - 0 inverse difference moment; Z - 0 entropy

Conclusions

- The greatest difference between the thin film samples and the control is exhibited by the inverse difference moment and entropy obtained with the ImageJ plug-in, and RMS obtained with the AFM tool.
- Three parameters obtained by ImageJ can be chosen to characterize the films due to strong correlation between RMS and standard deviation.
- Haralick statistics can potentially play an important role in the texture analysis of the dielectric and semiconductor thin films.

The authors thank Prof. T.P. Ma and Prof. M. L. Lee at Yale University for providing the Al₂O₃ and InGaAs material for this study.

Research supported by: NSF MRSEC / CRISP REU Program