Periodic variation of stress in sputter deposited Si/WSi$_2$ multilayers

Kimberley MacArthur (M.S. student, now at U. Tenn.),
Bing Shi (XSD),
Ray Conley (NSLS II, work done while in XSD),
Albert Macrander (XSD)

This work supported by U.S. Dept. of Energy, Office of Science. Office of Basic energy Sciences under contracts DE-AC02-06CH11357 and DE-AC02-98CH10886, and under Dept. of Energy Grant DE-FG02-07ER46380

TWG presentation Oct. 20, 2011
**Acknowledgments**

MLL development and measurement:

Sputtered thin film materials science:
R. Headrick, Y. Wang, H. Zhou, L. Zhou, M. Li
16 nm linear focus measured

WSi$_2$/Si, 1588 layers, $t_{\text{dep}} = 13.25$ $\mu$m

$\Delta r_{\text{max}} = 25$ nm

$\Delta r_{\text{min}} = 5$ nm

24 (H) x 27(V) nm² 2-D focus was obtained at 12 keV

In-situ x-ray reflectivity as 5 periods are built-up

FIG. 6. In situ x-ray reflectivity after each layer of the deposition of a WSi₂/Si multilayer. The numbers in the figure correspond to the numbers of layers at each stage.

Yi-Ping Wang, Hua Zhou, Lan Zhou, Randall Headrick, Albert Macrander, Ahmet Oczan
The interface roughness alternates!!

TABLE II. The thickness and roughness results for a WSi$_2$/Si multilayer with five periods.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness (nm)</th>
<th>Roughness (nm) as surface</th>
<th>Roughness (nm) as interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si layer (tenth layer)</td>
<td>6.0</td>
<td>0.39</td>
<td>...</td>
</tr>
<tr>
<td>WSi$_2$ layer (ninth layer)</td>
<td>6.4</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td>a-Si layer (eighth layer)</td>
<td>5.7</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>WSi$_2$ layer (seventh layer)</td>
<td>6.3</td>
<td>0.23</td>
<td>0.27</td>
</tr>
<tr>
<td>a-Si layer (sixth layer)</td>
<td>5.5</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>WSi$_2$ layer (fifth layer)</td>
<td>6.4</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>a-Si layer (fourth layer)</td>
<td>5.6</td>
<td>0.38</td>
<td>0.35</td>
</tr>
<tr>
<td>WSi$_2$ layer (third layer)</td>
<td>6.2</td>
<td>0.23</td>
<td>0.27</td>
</tr>
<tr>
<td>a-Si layer (second layer)</td>
<td>5.4</td>
<td>0.41</td>
<td>0.40</td>
</tr>
<tr>
<td>WSi$_2$ layer (first layer)</td>
<td>5.5</td>
<td>0.24</td>
<td>0.27</td>
</tr>
<tr>
<td>SiO$_2$ layer</td>
<td>0.5</td>
<td>0.25</td>
<td>0.26</td>
</tr>
<tr>
<td>Si substrate</td>
<td>...</td>
<td>...</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Delamination has to be avoided

**GISAX shows deposition in particles above 6 mTorr!**

Roughness increased dramatically above 6 mTorr

GISAX shows deposition in particles above 6 mTorr!

IN-SITU CURVATURE AND STRESS ANALYSIS FOR SPUTTERED WSi$_2$/Si MULTILAYER THIN FILMS ON SILICON WAFERS

BY

KIMBERLY CAITLIN MACARTHUR
© Kimberly Caitlin MacArthur

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF SCIENCE
First use reported in: Ray Conley, Chian Liu, Jun Qian, Cameron Kewish, Albert Macrander, Hanfei Yan, Hyon-Chol Kang, Jorg Maser, and G. B. Stephenson
Laser based curvature measurement system

(http://www.k-space.com)
Stoney’s Equation

\[ \sigma = \frac{E_s \cdot t_s^2}{6 \cdot (1 - \nu_s) \cdot t_f} \cdot K \]

Where \( \nu \) is Poisson’s ratio, \( E \) is Young’s modulus, \( t_s \) is substrate thickness, \( t_f \) is the film thickness, and \( K = \frac{1}{R} \) is the wafer curvature.

\[ \nu = -\frac{s_{12} + (s_{11} - s_{12} - \frac{1}{2} s_{44})(l_1^2 m_1^2 + l_2^2 m_2^2 + l_3^2 m_3^2)}{s_{11} - 2(s_{11} - s_{12} - \frac{1}{2} s_{44})(l_1^2 l_2^2 + l_2^2 l_3^2 + l_1^2 l_3^2)} \]
For Si(100) substrates, \((1-v)/E = s_{11} + s_{12}\) and is independent of the in-plane orientation. This implies that changes in curvature should be linear with thickness increments, i.e., with sputtering time.
Hor. And Vert. curvature changes are the same
Stress build depends strongly on Ar pressure
End point curvature after 20 periods

End point curvatures for other published materials

Fig. 1.39. Average internal stress versus argon pressure in Cr, Mo, Ni, Ta and stainless steel sputter-deposited films. Adapted from Thornton (1977), Hoffman and Thornton (1979) and Thornton et al. (1979).

Widely applied model to create tension

FIG. 4. Model for tensile stress generation due to continuous coalescence.

Si/WSi$_2$ multilayer curvature data

Curvature data collapsed onto time base for one period

Summary

The Si layers are the main source of high compressive stress at low Ar pressures. A clear way forward is to reduce the thickness of the Si layers, that is to change the $\gamma$ of the multilayer period.

Future MLL Work

(With additional team members: L. Gades, Il-Woong Jung, Curt Preissner, Dan Lopez, Jingtao Zhu, L. Assoufid)

- Two additional sputtering guns.
- Variation of multilayer $\gamma$
- MEMS