Periodic variation of stress in sputter deposited Si/WSi_2 multilayers

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Albert Macrander(XSD)

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TWG presentation Oct. 20, 2011

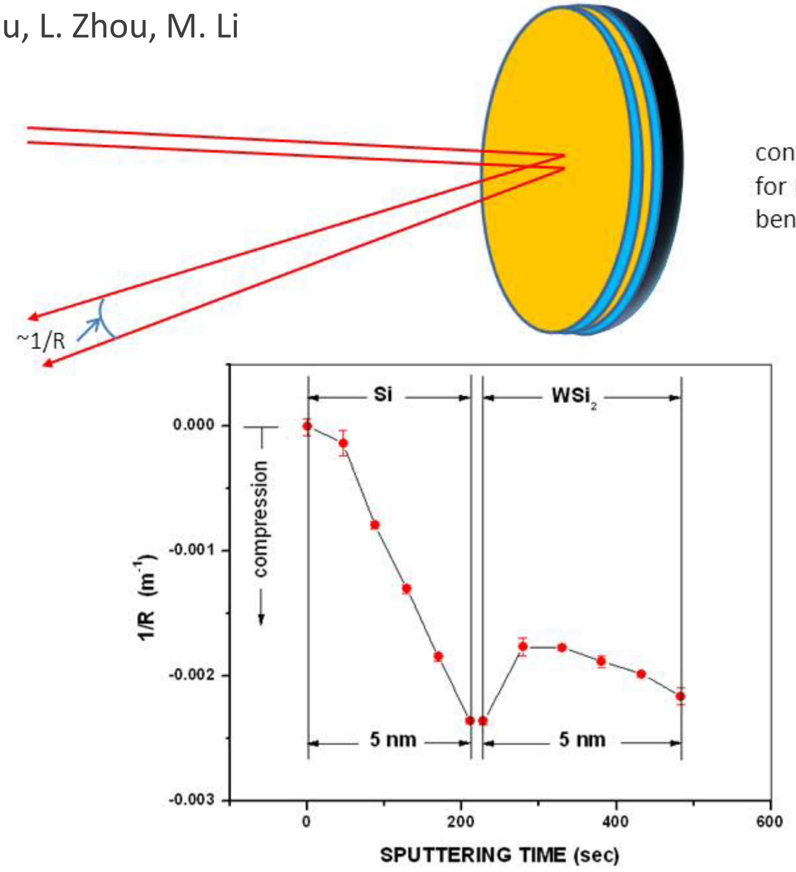
Acknowledgments

MLL development and measurement :

J. Maser, H. Yan, H-C Kang, R. Conley, C. Liu, N. Jahedi, G. B. Stephenson,
M. Holt, Y. S. Chu, V. Rose, D. Shu, E. Lima

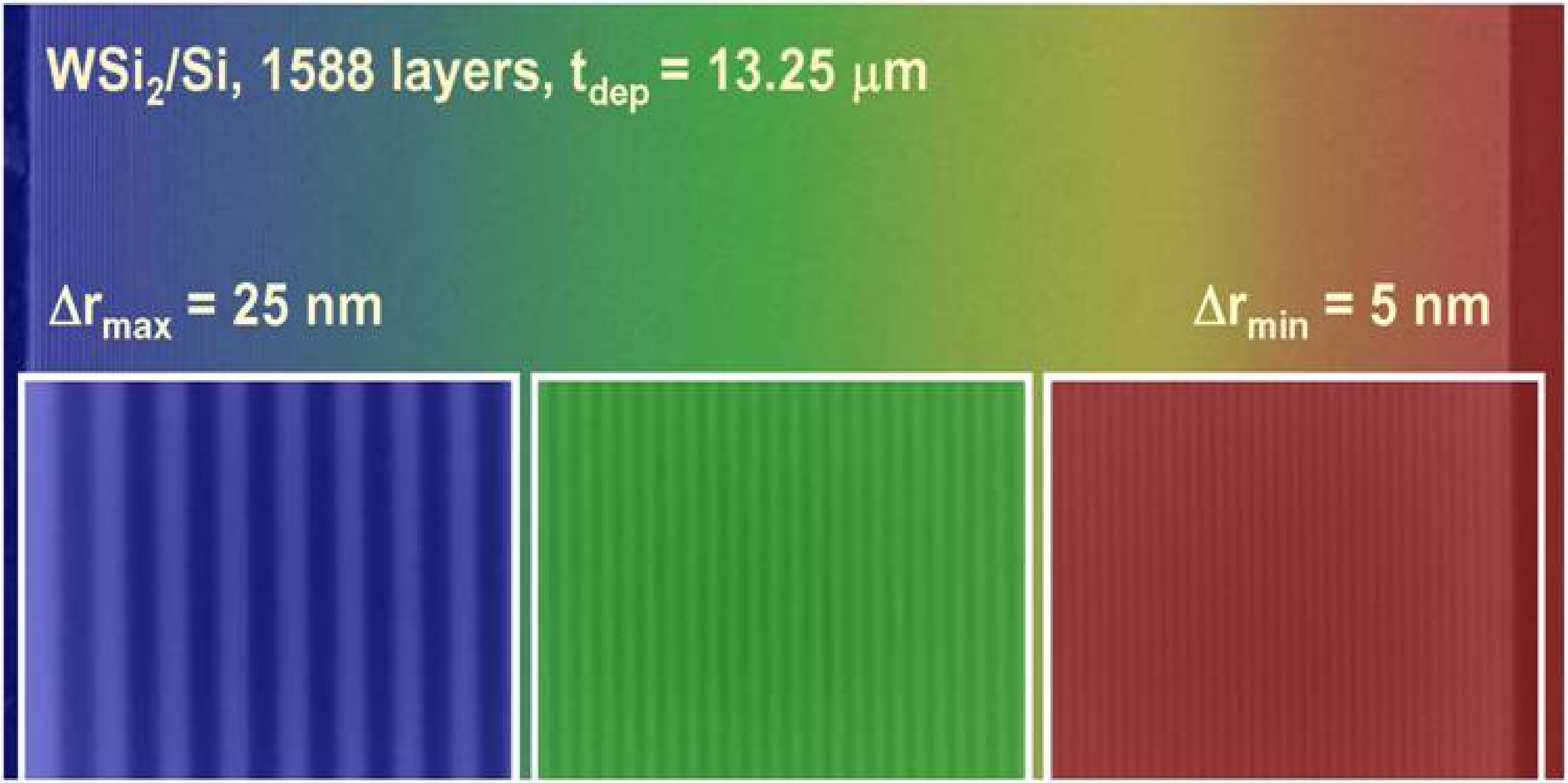
Sputtered thin film materials science:

R. Headrick, Y. Wang , H. Zhou, L. Zhou, M. Li



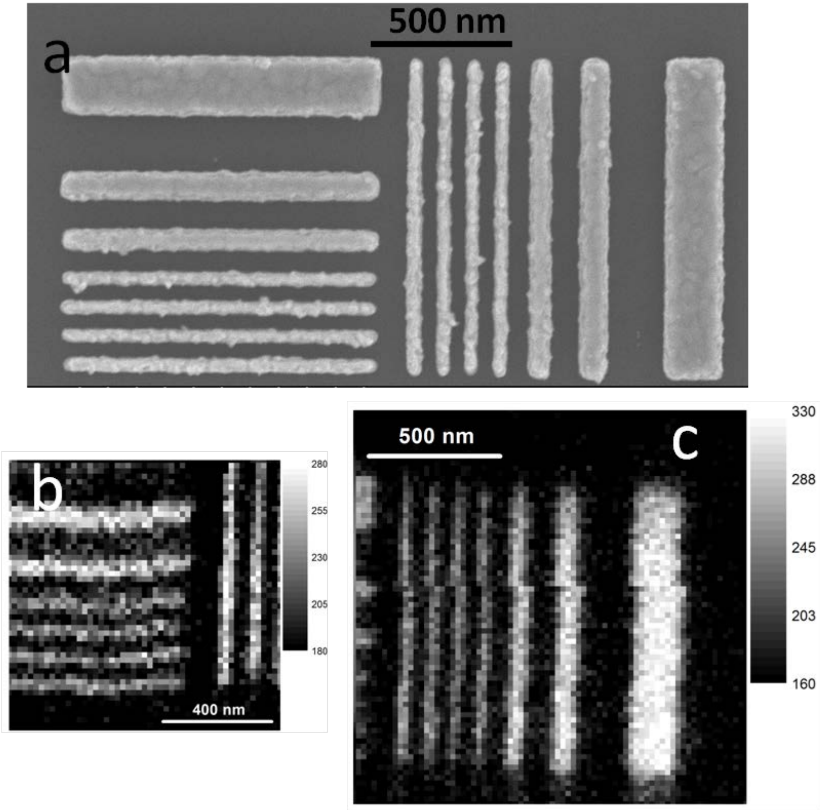
convex bending
for multilayer in compression,
bending radius = R

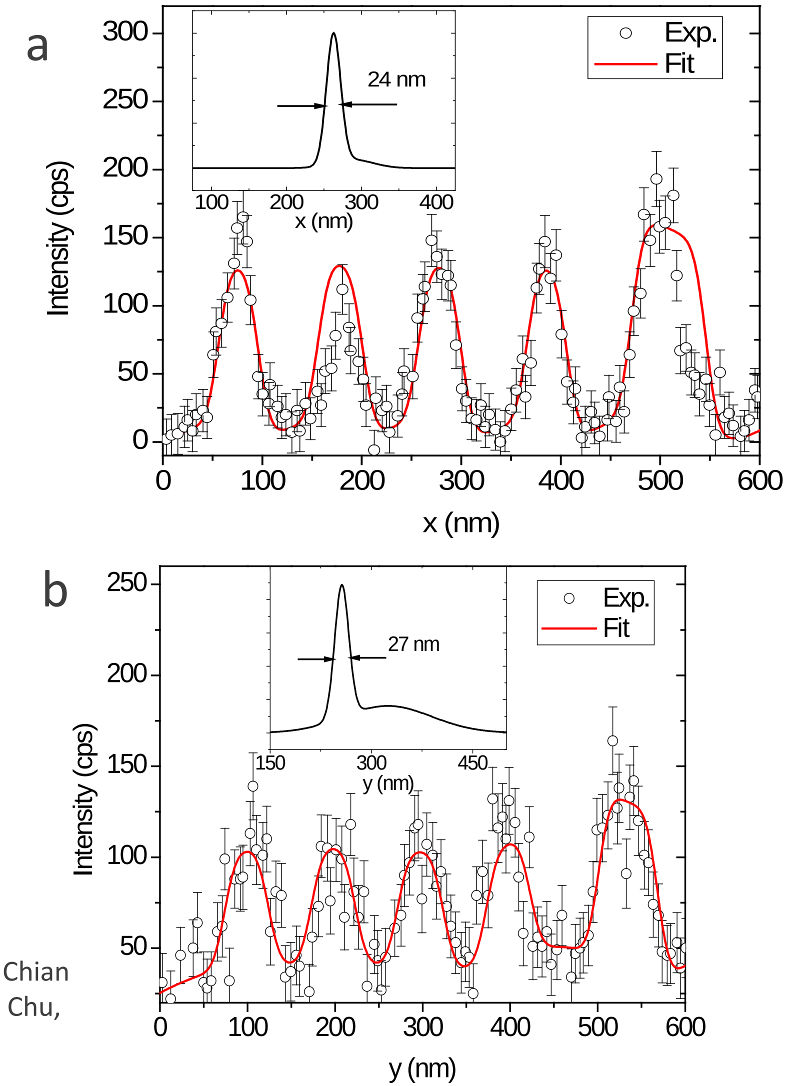
16 nm linear focus measured



H.C. Kang et al., Appl. Phys. Lett. 92, 221114 (2008)

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





Hanfei Yan, Volker Rose, Deming Shu, Enju Lima, Hyon Chol Kang, Ray Conley, Chian Liu, Nima Jahedi, Albert Macrander, G. Brian Stephenson, Martin Holt, Yong S. Chu, and Jorg Maser, Optics Express 19, 15069 (2011).

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

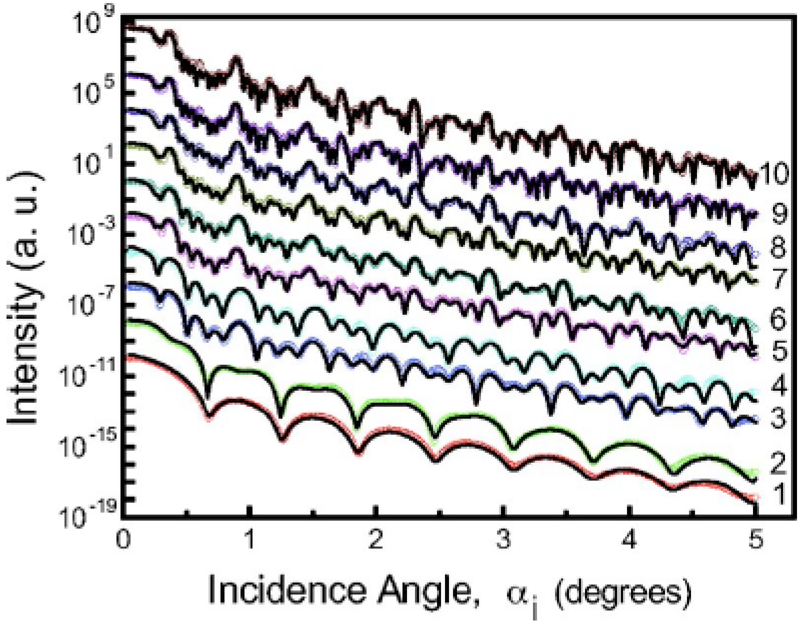


FIG. 6. *In situ* x-ray reflectivity after each layer of the deposition of a WSi_2/Si multilayer. The numbers in the figure correspond to the numbers of layers at each stage.

Yi-Ping Wang, Hua Zhou, Lan Zhou, Randall Headrick, Albert Macrander, Ahmet Oczan
J. Appl. Phys. 101, 023503 (2007)

The interface roughness alternates !!

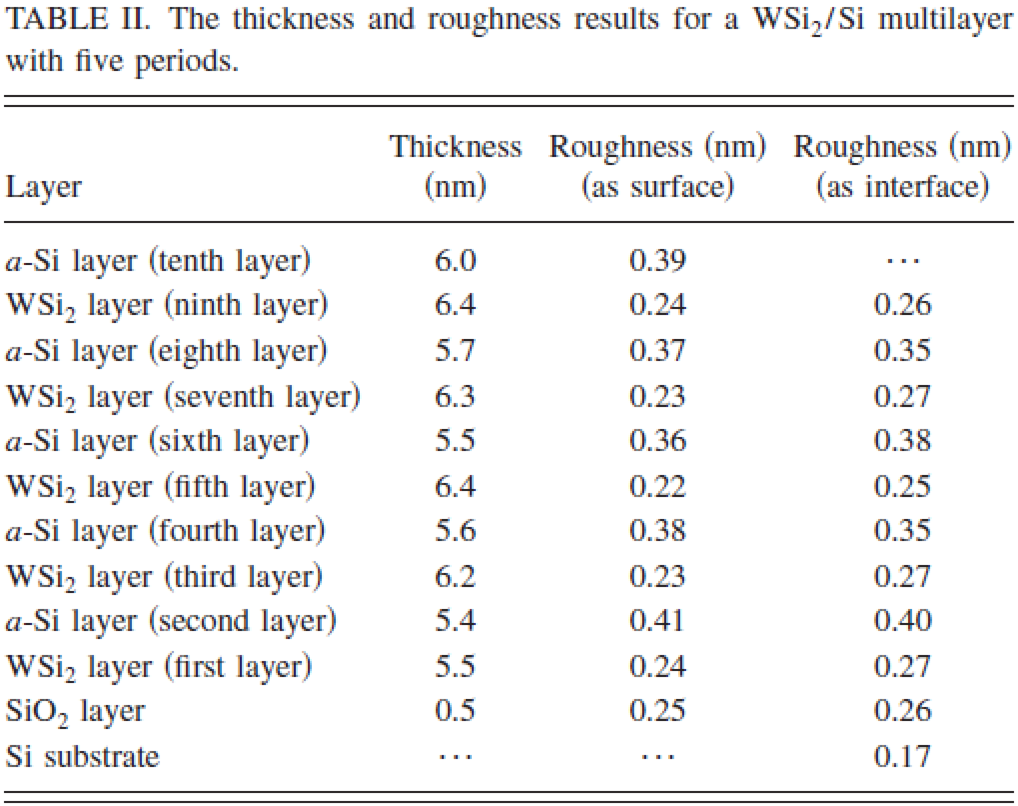
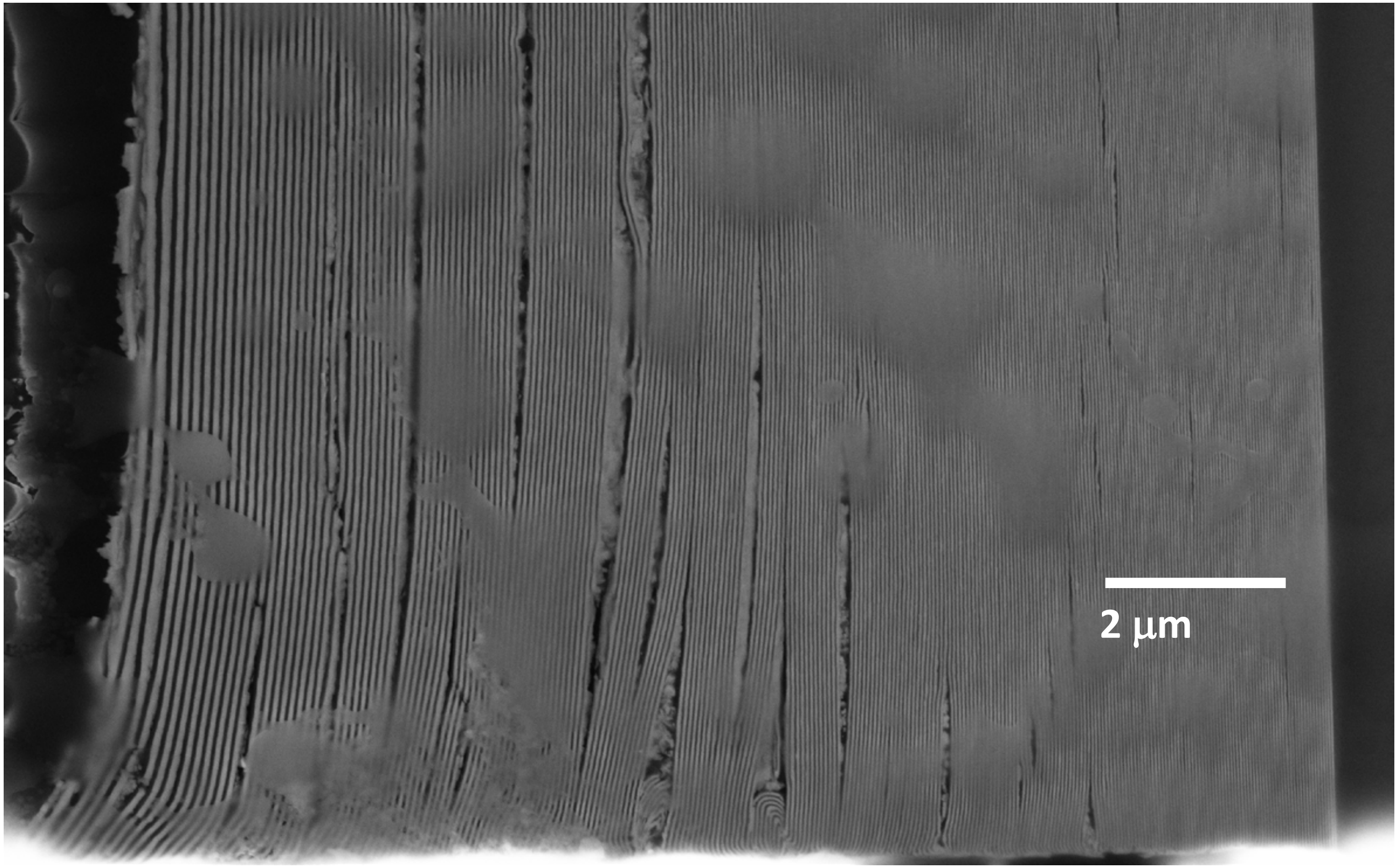


TABLE II. The thickness and roughness results for a WSi_2/Si multilayer with five periods.

Layer	Thickness (nm)	Roughness (nm) (as surface)	Roughness (nm) (as interface)
a-Si layer (tenth layer)	6.0	0.39	⋯
WSi_2 layer (ninth layer)	6.4	0.24	0.26
a-Si layer (eighth layer)	5.7	0.37	0.35
WSi_2 layer (seventh layer)	6.3	0.23	0.27
a-Si layer (sixth layer)	5.5	0.36	0.38
WSi_2 layer (fifth layer)	6.4	0.22	0.25
a-Si layer (fourth layer)	5.6	0.38	0.35
WSi_2 layer (third layer)	6.2	0.23	0.27
a-Si layer (second layer)	5.4	0.41	0.40
WSi_2 layer (first layer)	5.5	0.24	0.27
SiO_2 layer	0.5	0.25	0.26
Si substrate	⋯	⋯	0.17

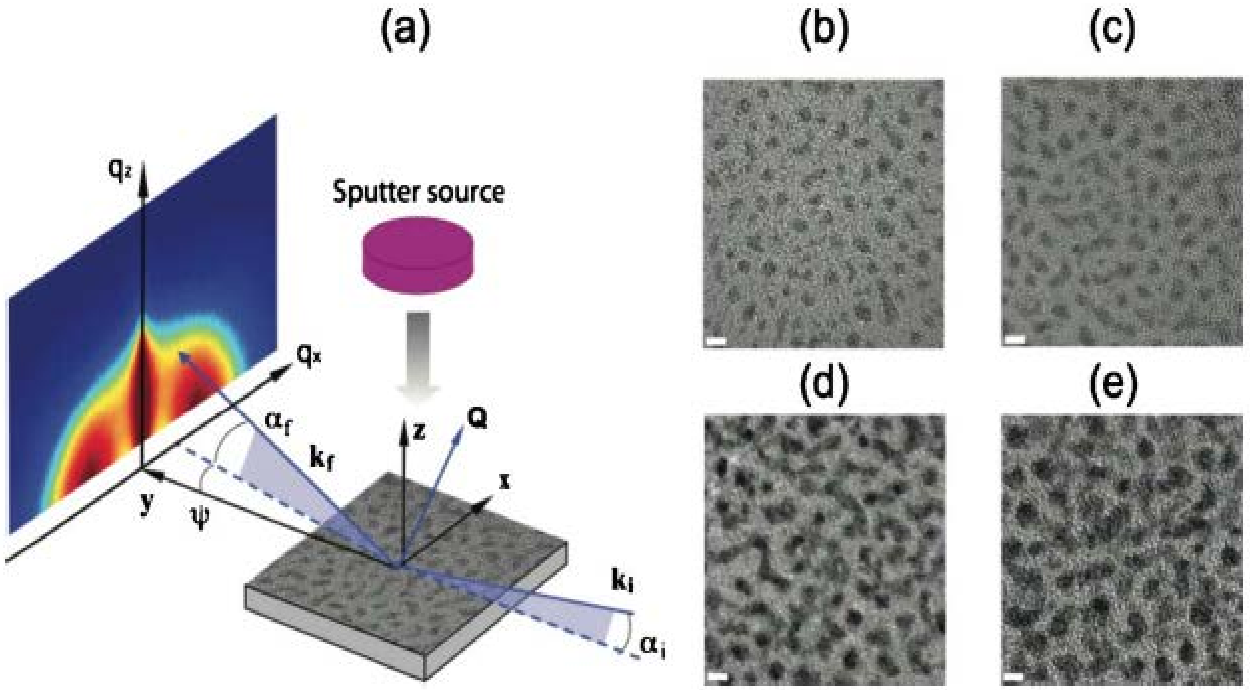
Yi-Ping Wang, Hua Zhou, Lan Zhou, Randall Headrick, Albert Macrander, Ahmet Oczan
J. Appl. Phys. 101, 023503 (2007)

Delamination has to be avoided



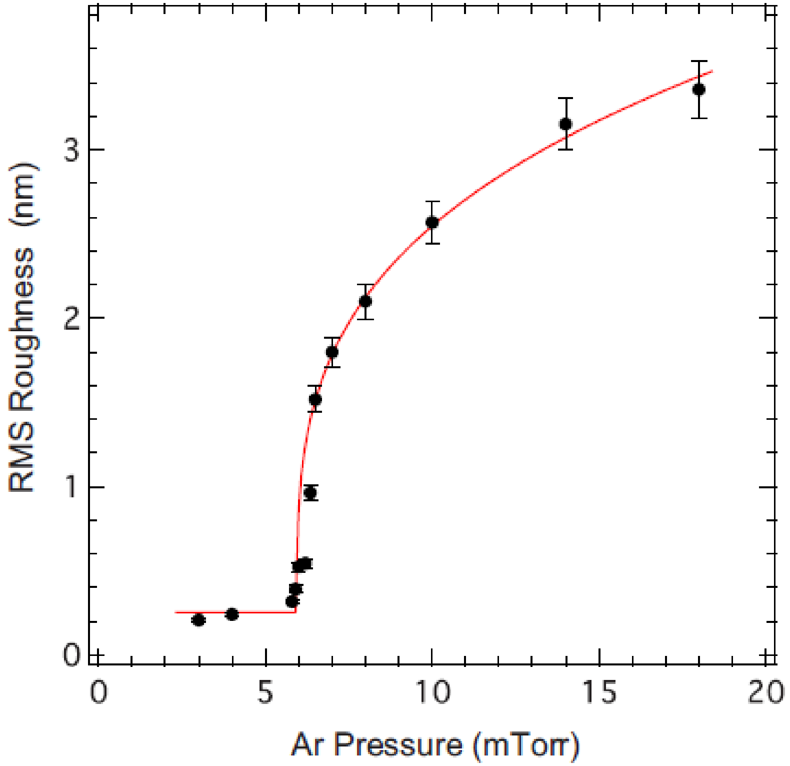
H.C. Kang, G.B. Stephenson, C. Liu, R. Conley, R. Khachatryan, M. Wieczorek,
A.T. Macrander, H. Yan, J. Maser, J. Hiller, R. Koratala, Rev. Sci. Instrum.78, 046103 (2007).

GISAX shows deposition in particles above 6 mTorr !



Lan Zhou, Yi-Ping Wang, Hua Zhou, Minghao Li, Randall Headrick, Kimberly MacArthur, Bing Shi, Ray Conley, and Albert Macrander, Phys. Rev. B 82, 075408 (2010)

Roughness increased dramatically above 6 mTorr



Lan Zhou, Yi-Ping Wang, Hua Zhou, Minghao Li, Randall Headrick, Kimberly MacArthur, Bing Shi, Ray Conley, and Albert Macrander, Phys. Rev. B 82, 075408 (2010)

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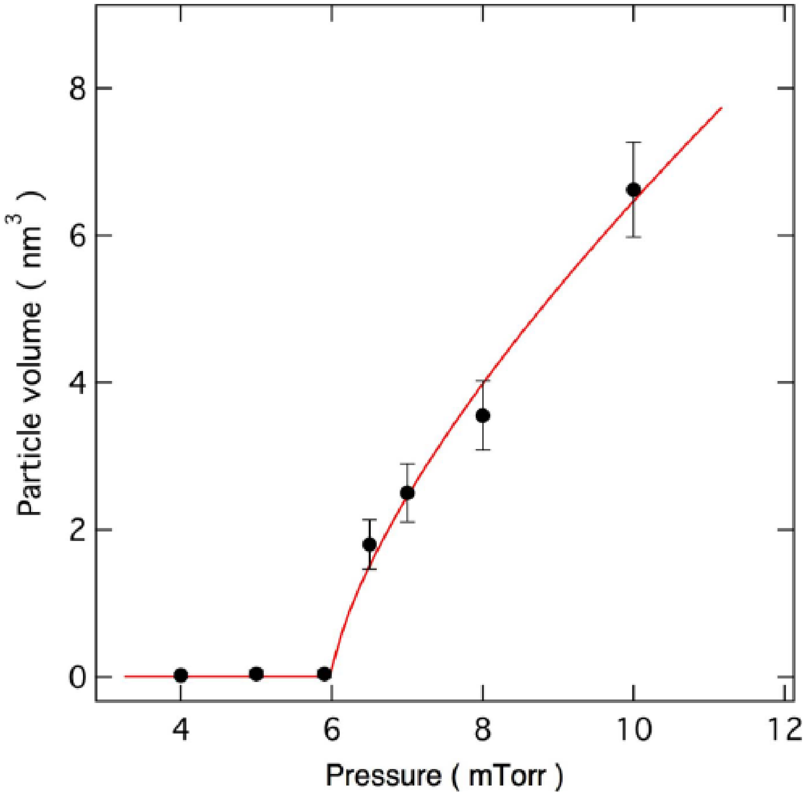


Lan Zhou, Yi-Ping Wang, Hua Zhou, Minghao Li, Randall Headrick, Kimberly MacArthur, Bing Shi, Ray Conley, and Albert Macrander, Phys. Rev. B 82, 075408 (2010)

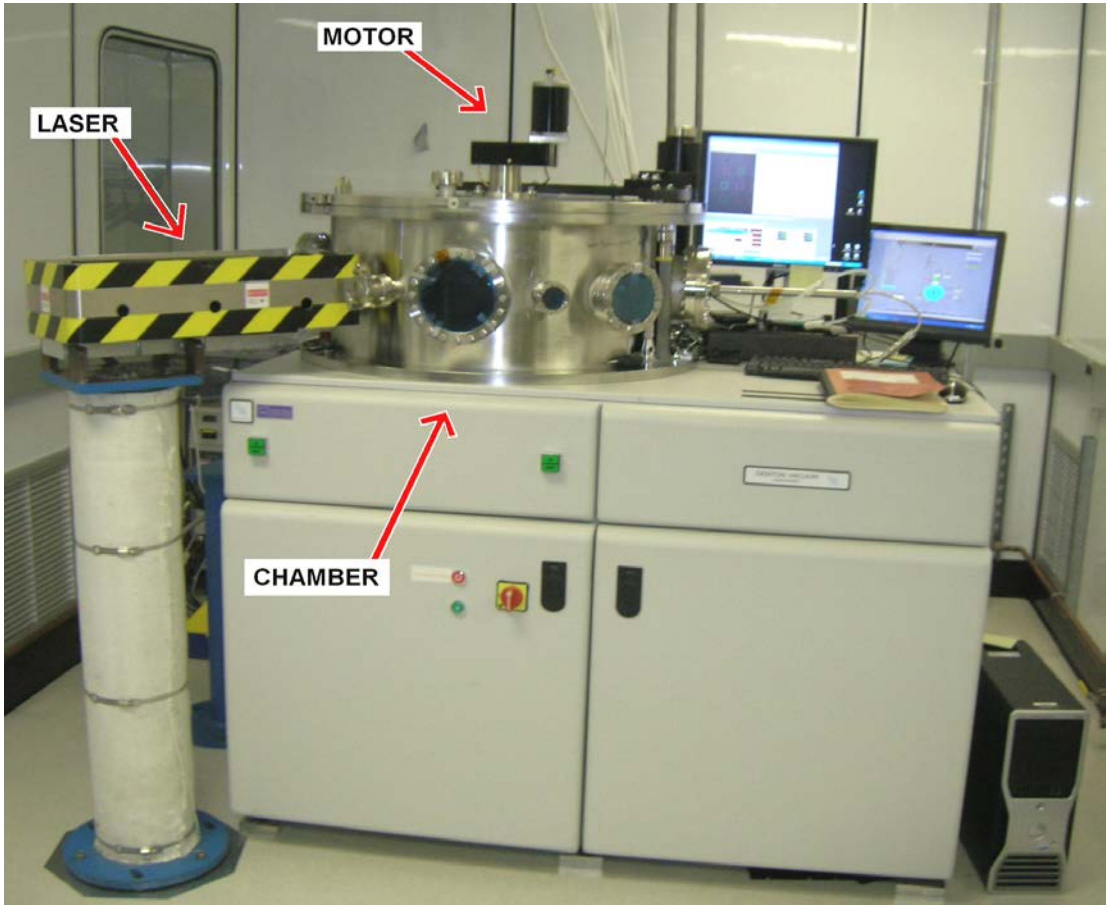
NORTHERN ILLINOIS UNIVERSITY
DE KALB, ILLINOIS
MAY 2010

IN-SITU CURVATURE AND STRESS ANALYSIS FOR SPUTTERED WSi_2/Si MULTILAYER THIN FILMS ON SILICON WAFERS

BY
KIMBERLY CAITLIN MACARTHUR

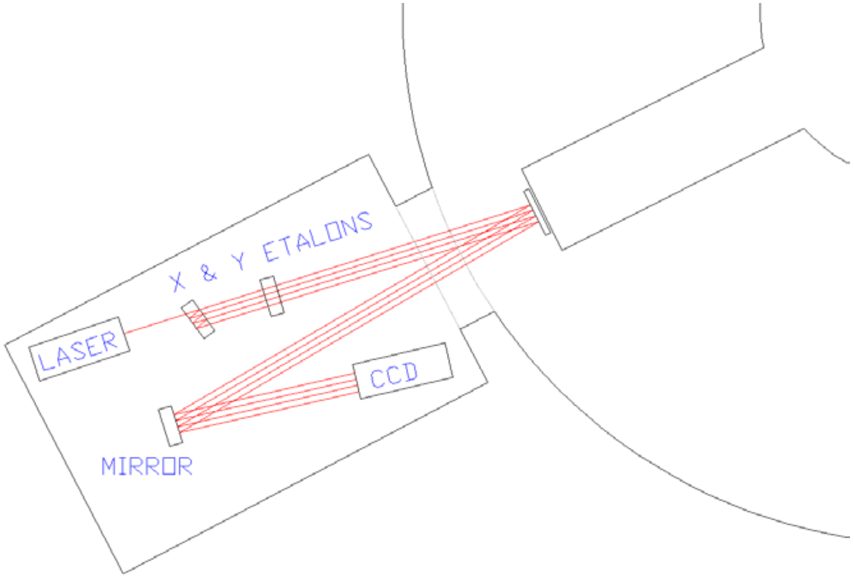
A THESIS SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER OF SCIENCE

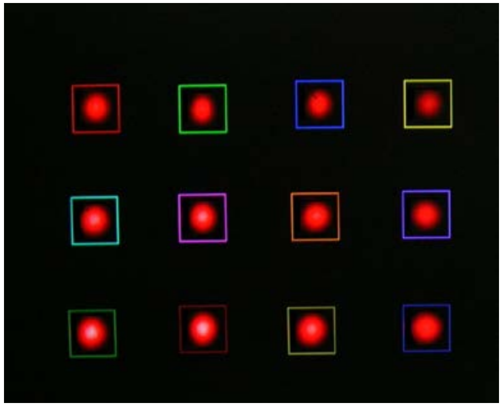
APS rotary sputter deposition system

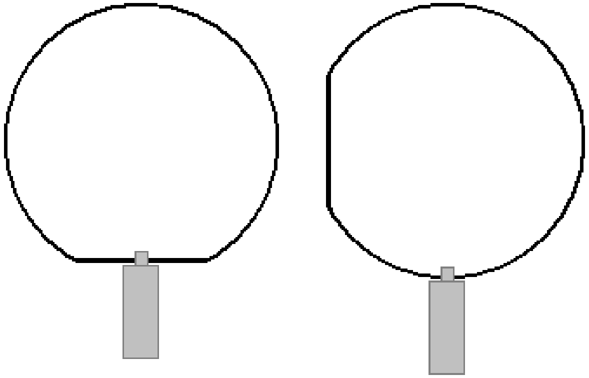


First use reported in : Ray Conley, Chian Liu, Jun Qian, Cameron Kewish, Albert Macrander, Hanfei Yan, Hyon-Chol Kang, Jorg Maser, and G. B. Stephenson Rev. Sci. Instrum. 79, 053104 (2008)

Laser based curvature measurement system







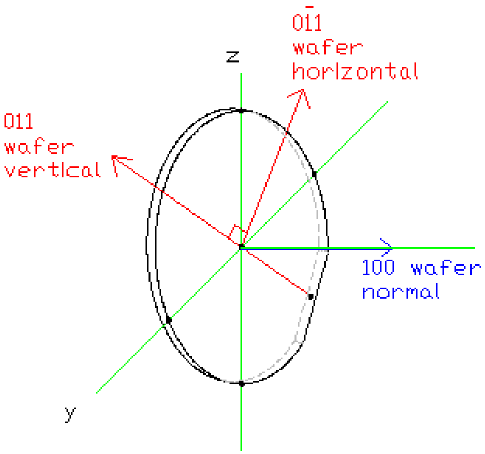
(http://www.k-space.com)

Stoney's Equation

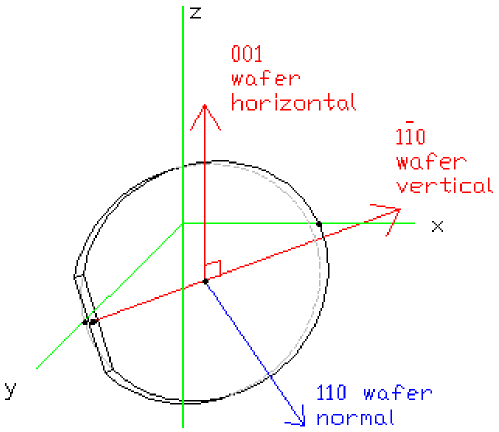
$$\sigma = \frac{E_s \cdot t_s^2}{6 \cdot (1 - \nu_s) \cdot t_f} \cdot \mathrm{K}$$

Where ν Poisson's ratio, E is Young's modulus, t_s is substrate thickness, t_f is the film thickness, and K =1/R is the wafer curvature

$$\nu = -\frac{s_{12} + (s_{11} - s_{12} - \frac{1}{2}s_{44})(l_1^2 m_1^2 + l_2^2 m_2^2 + l_3^2 m_3^2)}{s_{11} - 2(s_{11} - s_{12} - \frac{1}{2}s_{44})(l_1^2 l_2^2 + l_2^2 l_3^2 + l_1^2 l_3^2)}$$



100
wafer on yz plane



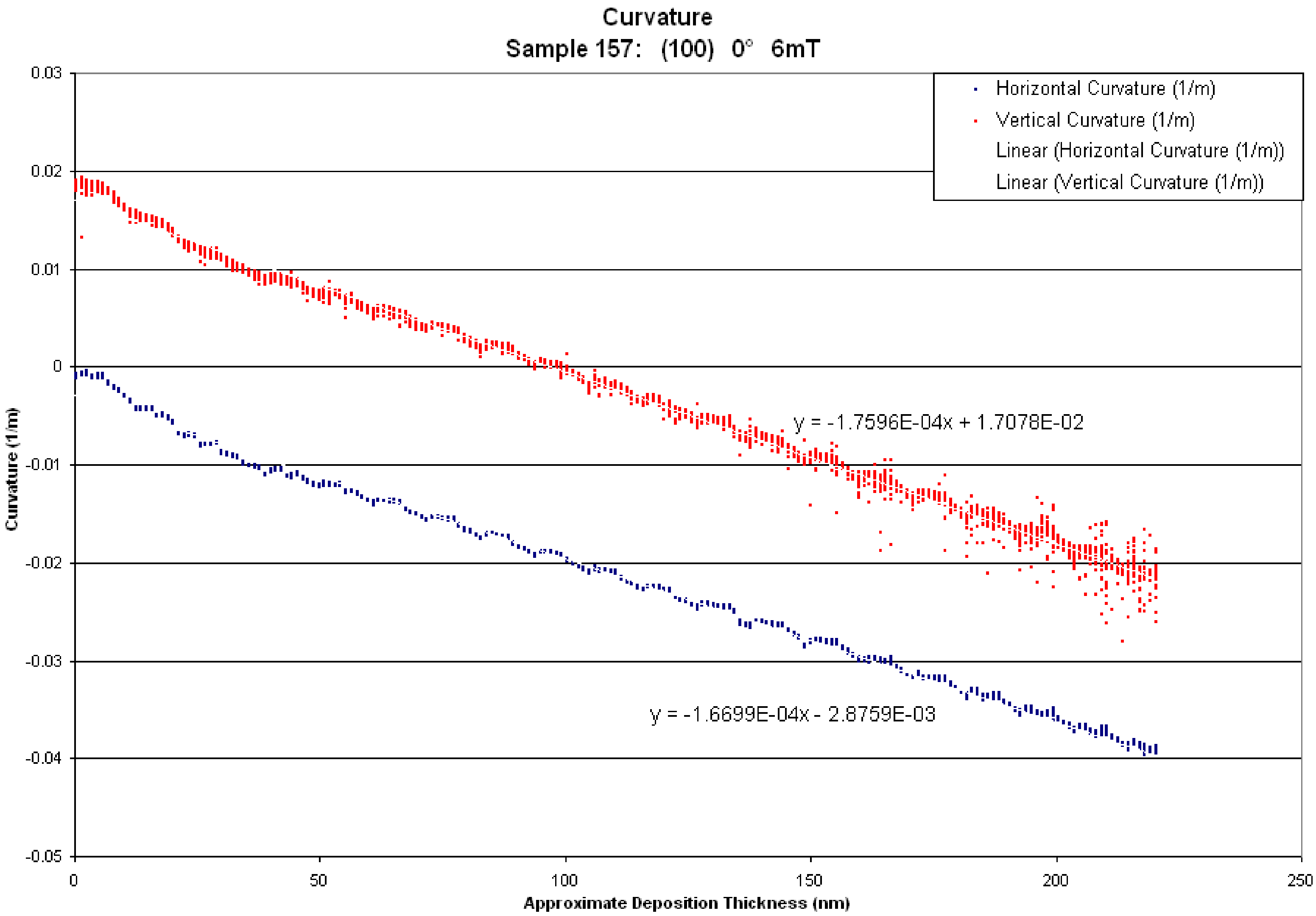
110 wafer

Stoney's equation in the form we can apply:

$$\delta\left(\frac{1}{R}\right) = 6\sigma\left(\frac{1-\nu}{E}\right)\frac{\delta(t_f)}{t_s^2}$$

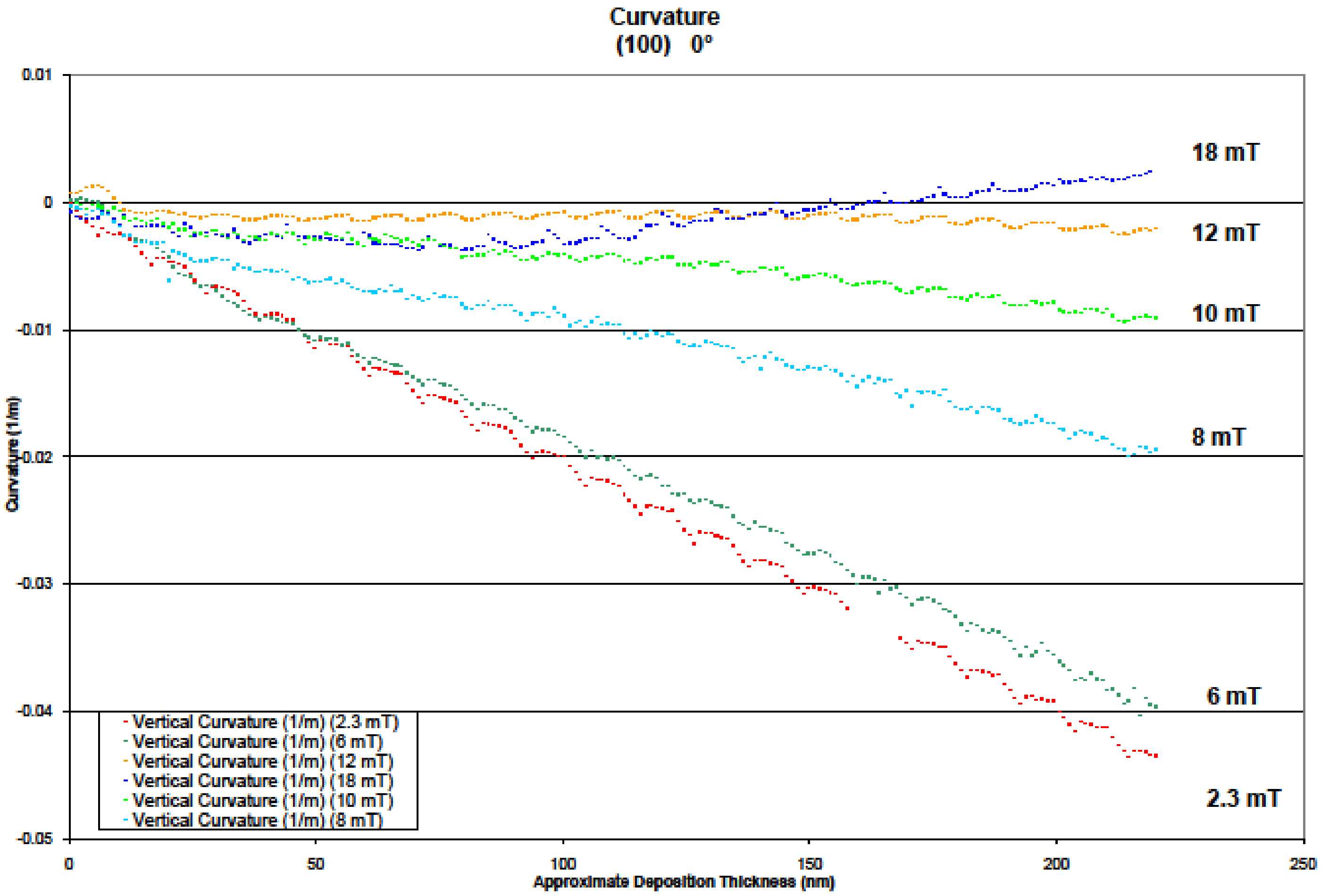
For Si(100) substrates, $(1-\nu)/E = s_{11} + s_{12}$ and is independent of the in-plane orientation. This implies that changes in curvature should be linear with thickness increments ,i.e., with sputtering time.

Hor. And Vert. curvature changes are the same



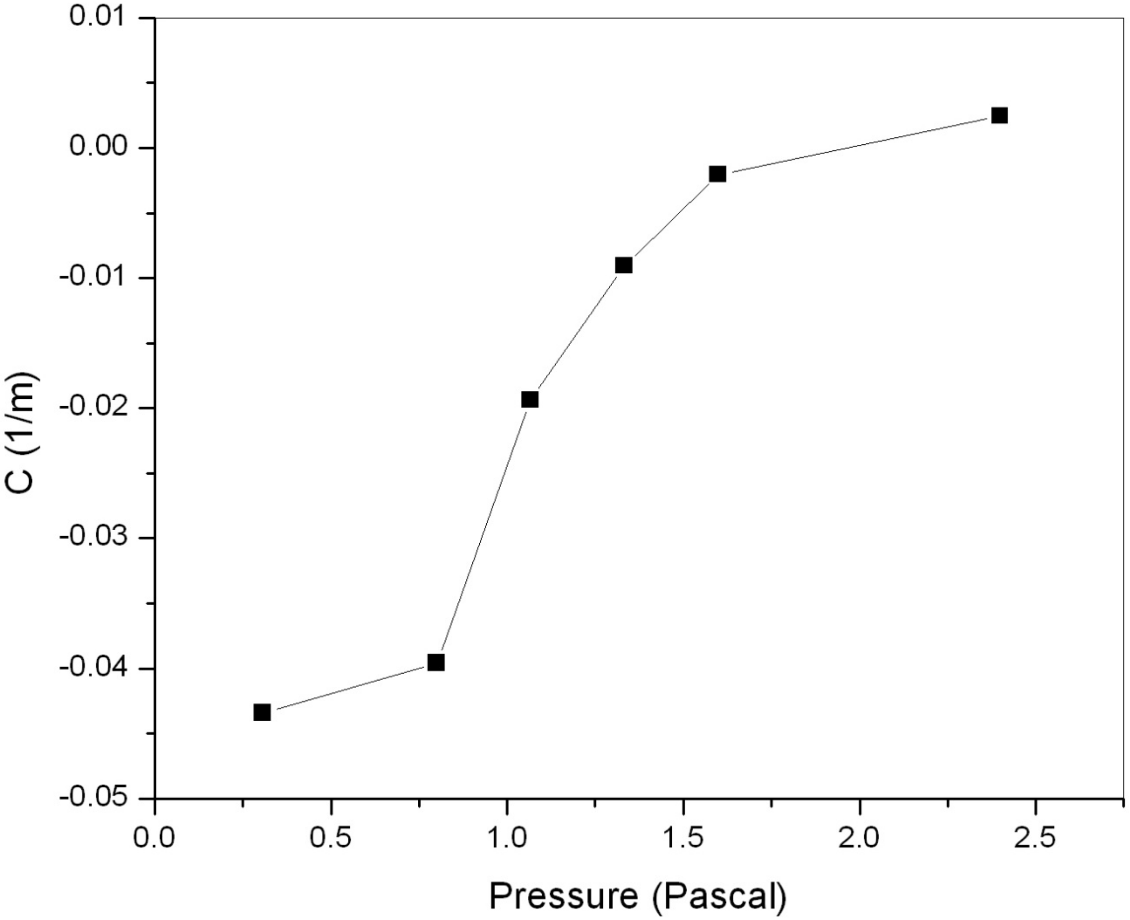
Stress build depends strongly on Ar pressure

(100) 0 Vonly AVGd



Page 1

End point curvature after 20 periods



Lan Zhou, Yi-Ping Wang, Hua Zhou, Minghao Li, Randall Headrick, Kimberly MacArthur, Bing Shi, Ray Conley, and Albert Macrander, Phys. Rev. B 82, 075408 (2010)

End point curvatures for other published materials

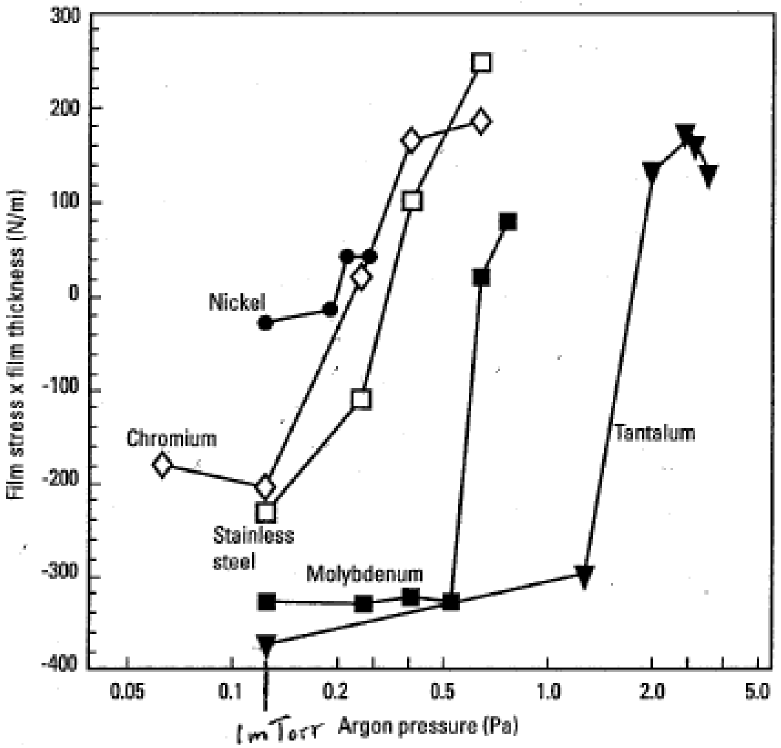


Fig. 1.39. Average internal stress versus argon pressure in Cr, Mo, Ni, Ta and stainless steel sputter-deposited films. Adapted from Thornton (1977), Hoffman and Thornton (1979) and Thornton et al. (1979).

L.B. Freund and S. Suresh, "Thin Film Materials: Stress, Defect Formation and Surface Evolution", Cambridge Press, 2003

Widely applied model to create tension

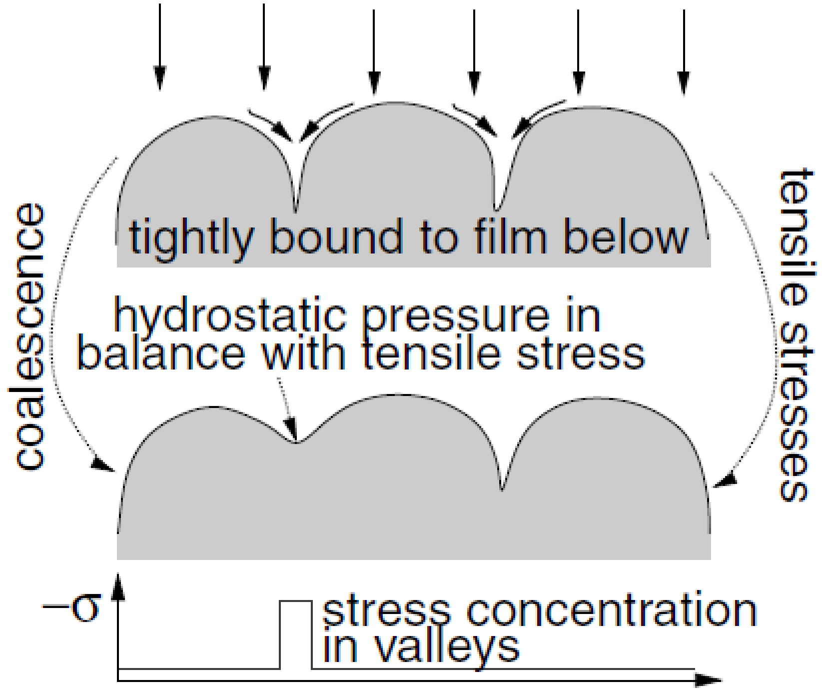
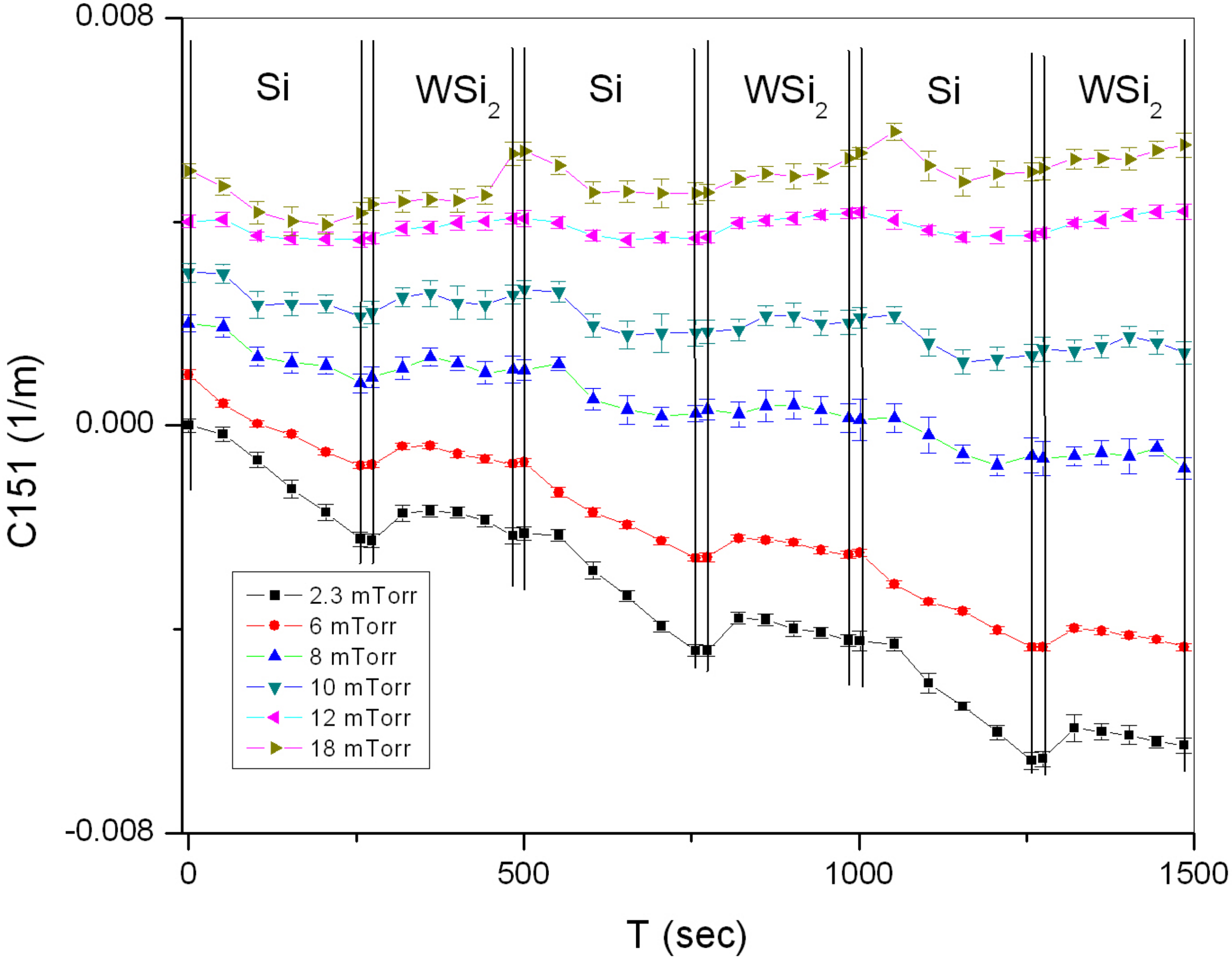


FIG. 4. Model for tensile stress generation due to continuous coalescence.

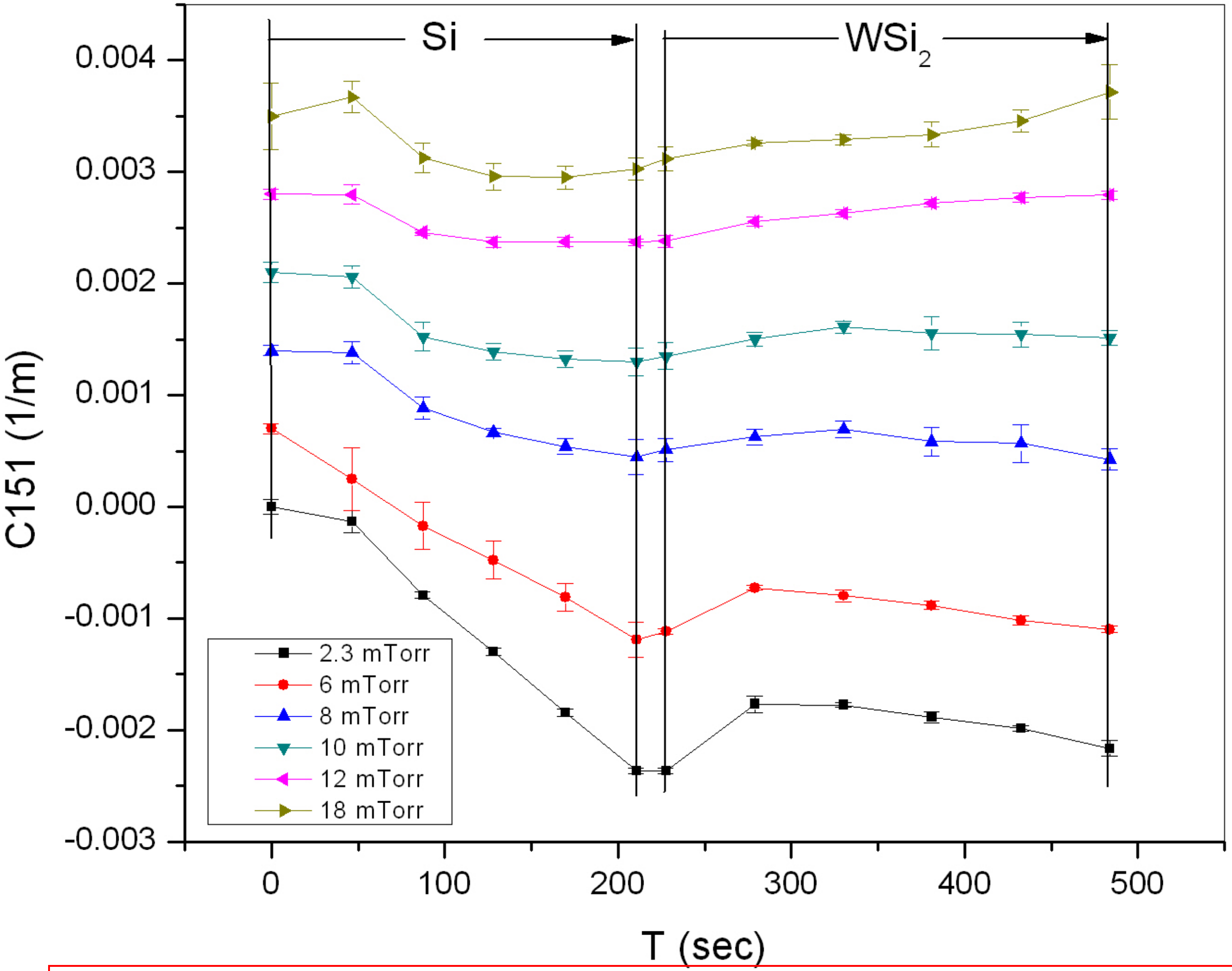
S.G. Mayr and K. Sanwer, Phys. Rev. Lett. 87, 036105 (2001).

Si/WSi$_2$ multilayer curvature data



K. MacArthur, B. Shi, R. Conley, and A. Macrander, Appl. Phys. Lett. 99, 081905 (2011)

Curvature data collapsed onto time base for one period



K. MacArthur, B. Shi, R. Conley, and A. Macrander, Appl. Phys. Lett. 99, 081905 (2011)

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 γ 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 γ
- MEMS