Some unpleasant truth about certain dynamic/oscillatory measurement procedures

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What is wrong with CSM and Co.? How to come from dynamic measurement to real - and correct - depth profiles?

Motivation

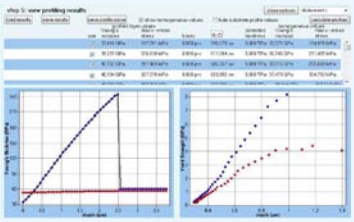
Example: Nanoindentation into low-k on Si

Questionable results:

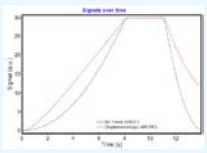
	using CSM at lower loads	using single indent at same max load
E_{eff}	2,8GPa	3,6GPa
H	1,45GPa	0,75GPa

Why do we obtain different results despite using the same indenter, sample, and area function?

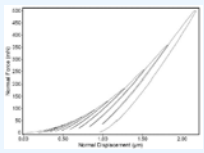
Goal: Coming to a true (?) depth profile for Young's modulus and Yield strength



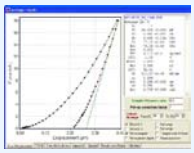
Classical quasi-static indentation methods



normal indentation



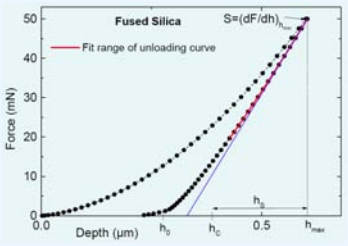
cyclic measurements



acc. to ISO14577

and some others like fully elastic indentations

From quasi-static to dynamic measurements



The contact depth h_c is determined with the help of a model (assuming a homogeneous halfspace) from the maximum depth and the contact stiffness S at maximum load.

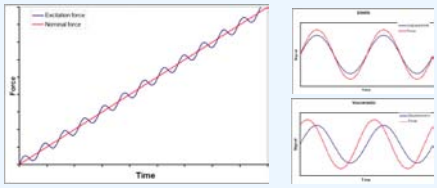
Therefore, indentation hardness and modulus can only be determined if the contact stiffness is measured.

$$S = \frac{dF}{dh} \approx \frac{\Delta F}{\Delta h}$$

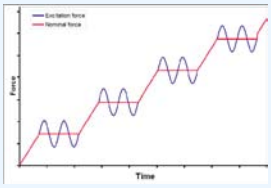
But with the **CSM or QCSM method**, the contact stiffness is measured already **during loading** as quotient of force amplitude and displacement amplitude of a small oscillation.

Classic dynamic methods and profiling?

CSM method of Nanoinstruments (Agilent)



QCSM method of ASMEC

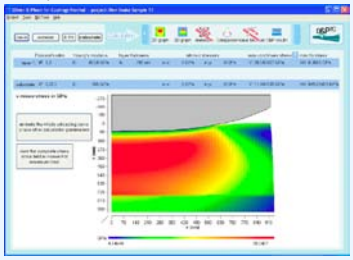


For both: Still no true depth property profiling possible, because of lack of a proper model. → Thus, all „CS-Methods" are flawed in many ways!

Main flaws of classical dynamic measurements and their solutions

1. Dynamic measurement analysis is based on half space theory, but the sample being of interest is inhomogeneous – this cannot work properly.

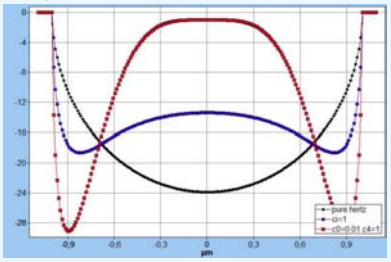
Example:



Solution: SIO's correct layered half space model ensures correct analysis by taking coating structure into account

2. Dynamic measurement only ever gives S at a certain loading point, because there is no complete or at least partial unloading.

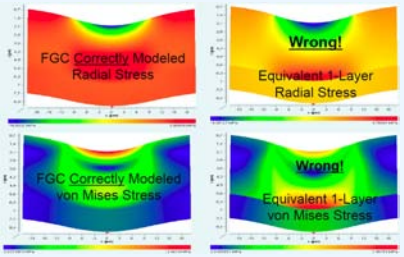
Example:



Solution: SIO's correct layered half space model ensures correct analysis and allows evaluation of surface stress beneath indenter correctly

3. This unknown unloading information at each point also compels you to make assumptions for the stress distribution flawing all further conclusions

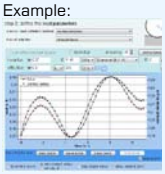
Substantiation:



Solution: SIO's model also allows evaluation of complete stress field under the indenter in complex layered structures

4. The change of contact radius during oscillation is ignored, which is a problem for smaller total or ramp loads.

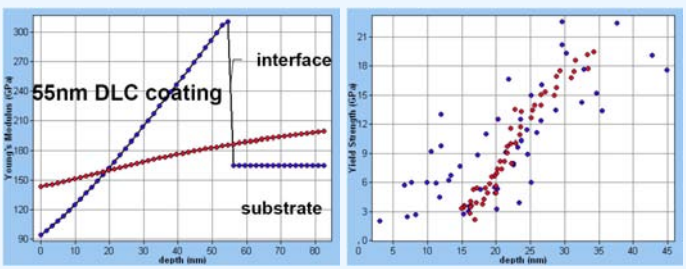
Example:



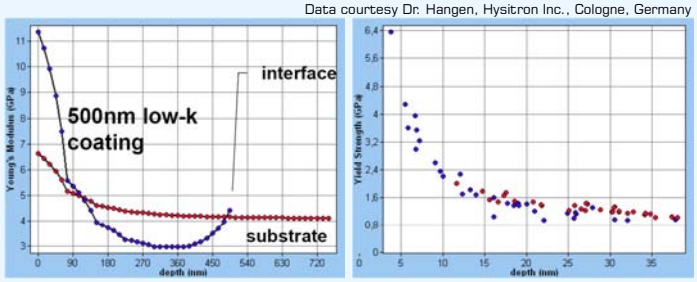
Solution: SIO's viscous models (also layered if required) take the change of contact radius during each oscillation circle into account

If analyzed correctly, dynamic measurements can provide true depth property profiles of complex coating structures

Data courtesy Dr. Hangen, Hysitron Inc., Cologne, Germany



Young's modulus profile (left) and Yield strength profile (right) as function of **real** depth



Young's modulus profile (left) and Yield strength profile (right) as function of **real** depth

Conclusions

Classical analysis of dynamic / oscillatory measurement procedures is flawed in many ways but after correction we can extract:

- Real depth profile
- True surface/coating parameters

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References

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