Comparison between Vickers Hardness and Indentation Hardness

T. Chudoba, M. Griepentrog, U. Beck

Federal Institute for Materials Research and Testing (BAM), D-12200 Berlin, Germany

Introduction

The Vickers hardness is an often used hardness definition, mainly in the force range above 0.5 N. With decreasing film thickness and the need of lower loads, depth and force sensing measurement techniques became more and more important and a new indentation hardness was introduced, finally resulting in the international standard ISO 14577. Therefore investigations regarding the comparability of both hardness definitions are of high interest. In principle it should be possible to obtain the same hardness number with both measurement methods if the true contact area can be determined. The agreement is checked for a large selection of materials and instruments for a force of 0.5 N ($HV_{0.051}$). The calculation of the correct contact area from depth sensing measurements is also checked by a comparison of the indentation modulus with the Young's modulus, obtained with other methods.

Theory

Vickers hardness: $HV = 0.1891 \cdot \frac{F}{d^2}$ d - Average of both diagonal lengths, F- Force

The Vickers hardness is related to the surface contact area of an ideal pyramid

Indentation hardness: $H_{IT} = \frac{F}{A_P(h_c)}$ ideal: $A_P = 24.5 \cdot h_c^2$ $h_c = h_{max} - \varepsilon \cdot \frac{F}{S}$

h_{max} - Maximum depth h_C - Contact depth
S - Contact stiffness

The Indentation hardness is related to the projected contact area A_P. For real pyramids an area function $A_P(h_C)$ is required. The epsilon factor is 0.75 for a Vickers pyramid (Fischerscope software uses epsilon = 1)

Correlation between Vickers and Indentation hardness: $HV = 0.094545 \cdot H_{IT}$ The factor contains the transformations of contact into surface area and of the unit MPa into kp/mm²

Additional corrections for Indentation hardness: They are used in the data analysis software **Indent Analyser (ASMEC)**

Variable epsilon factor: Epsilon depends on the exponent **m** of the unloading curve (if fitted with a power function) and may vary between 0.7 and 0.8

Radial elastic displacement correction: It considers the radial elastic displacement of the contact area under load in relation to the unloaded state and depends on the Hardness/Modulus ratio. It is close to zero for metals and may reach 10% in maximum.

Investigated materials and references

List of Materials	Sorce	HV	Reference	E	Reference
Fused Silica	EU project DESIRED	706	BAM measurement	72	INDICOAT measurement
Sigadur, glassy carbon	EU project DESIRED	374	BAM measurement	27	Measurement average (*)
Zerodur glass	EU project DESIRED	858	BAM measurement	80	Measurement average (*)
K7 glass	EU project DESIRED	546	BAM measurement	70	Literature (*)
Si(100) single crystal	TU Chemnitz	1193	BAM measurement	168	Literature
Tungsten single crystal	EU project DESIRED	415	BAM measurement	410	INDICOAT measurement
Tungsten poly crystal	EU project DESIRED	510	BAM measurement	410	Literature
Gold	EU project DESIRED	239	BAM measurement	78	Literature (*)
Nickel	EU project INDICOAT	154	BAM measurement	200	Literature
Al single crystal	EU project DESIRED	17.7	BAM measurement	70	Literature
M2 steel	EU project INDICOAT	863	BAM measurement	221	BAM measurement with SAW
100Cr6 steel	BAM sample	903	BAM measurement	204	BAM measurement with SAW
S21 steel	BAM, X8CrMnN18-18	304	BAM measurement	198	BAM measurement with SAW
S6-5-2 steel	BAM sample	1037	BAM measurement	219	BAM measurement with SAW
Sapphire	EU project DESIRED	2232	BAM measurement	420	Literature, measurement average (*)
Silicon Nitride	EU project DESIRED	1841	BAM measurement	300	Literature, measurement average (*)
Hardmetal	Widia GmbH	2850	MPA Dortmund	654	FhIWS measurement
Al2O3 ceramic	Fh IKTS Dresden	2419	BAM measurement	420	Literature (*)
SiC ceramic	Fh IKTS Dresden	2945	BAM measurement	450	Literature (*)
3µm TiN on 100Cr6	BAM sample	1481	BAM measurement	420	BAM measurement with SAW

SAW - Surface Acoustic Waves
(*) SAW measurements in preparation

Experimental

On each sample 10 measurements were done at 500mN with each instrument.
Indenter: Vickers (for all instruments)
Loading time 30 s (for all instruments beside UMIS-2000)
Hold period at maximum load: 12.5 s

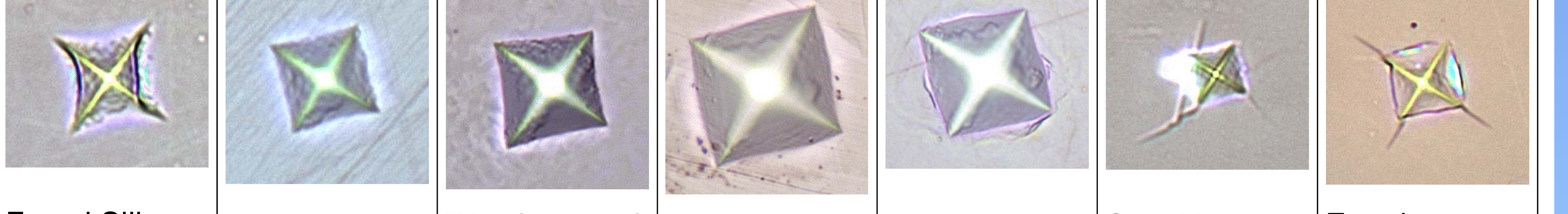
Vickers hardness: Tests were done with a Reichert-Jung Micro-Duromat 4000 and with trained operators. Magnification: 1000

Indentation hardness: Tests with Fischerscope (Helmut Fischer GmbH, Germany), Nanoindenter XP (MTS, USA), UMIS-2000 (CSIRO, Australia)

Results are converted into Vickers hardness with the formula above.

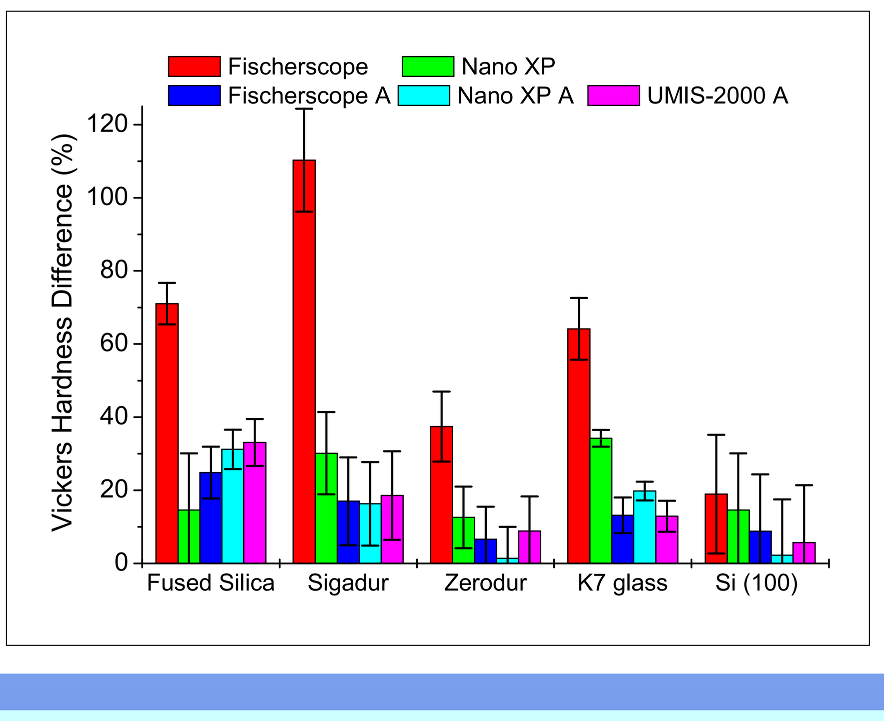
Calibration of area function with Fused Silica or BK7glass. Calibration of instrument compliance additionally with Sapphire. Both calibrations use Young's modulus as reference.
Data analysis with standard software for Fischerscope and Nanoindenter XP and additionally with the software Indent Analyser (ASMEC) for all instruments. These analysis is marked with an **A** after the instrument name in the diagrams.

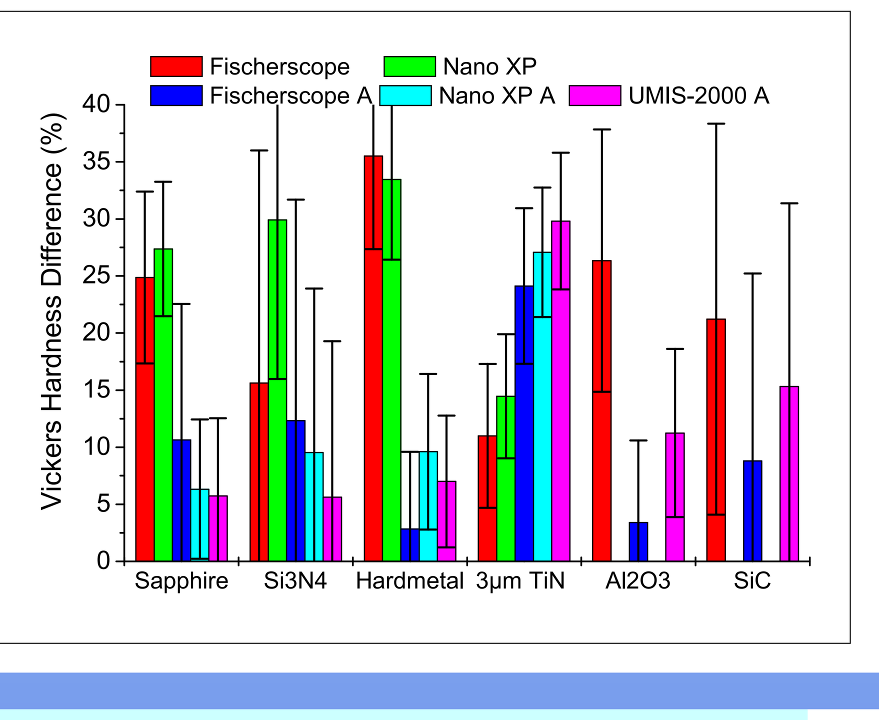
Examples for indents

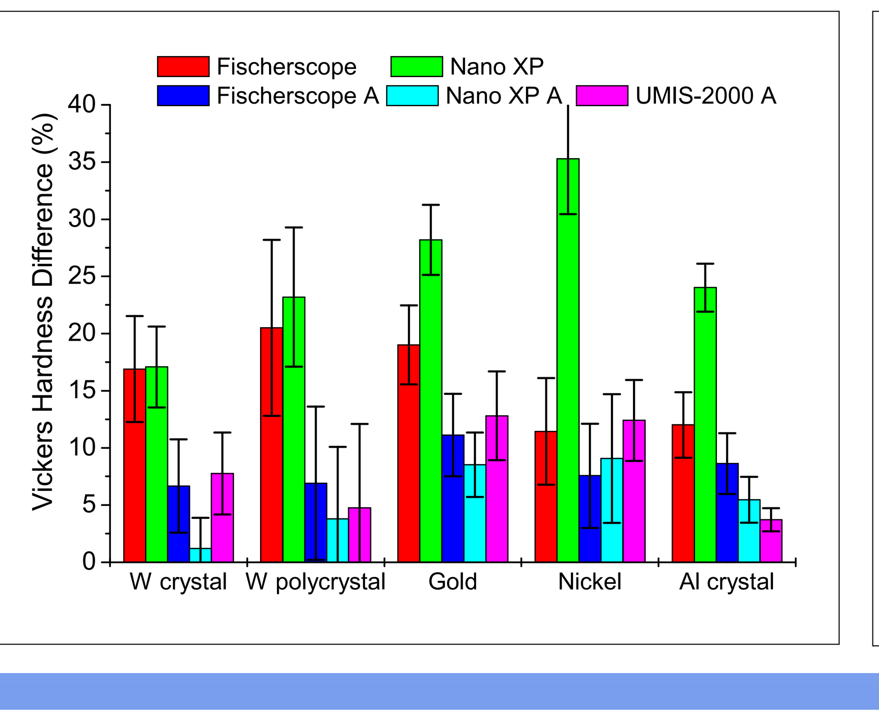


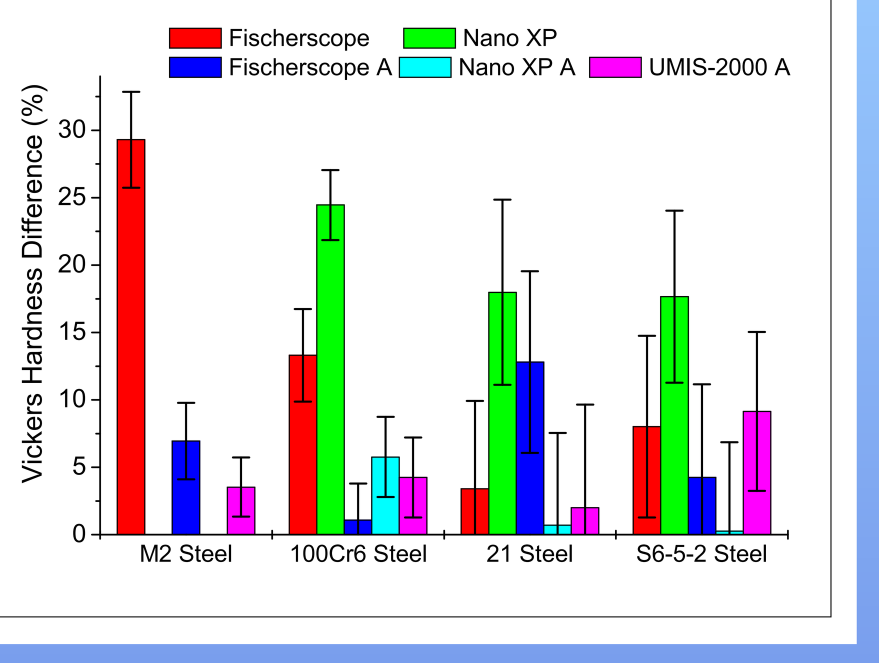
Fused Silica Cushion shape | 100Cr6 steel Pile-up occur | W poly-crystal Non symmetric | Nickel Pile-up occur | Gold Pile-up occur | Sapphire Cracks occur | Zerodur Cracks occur

Hardness comparison (difference to table value)

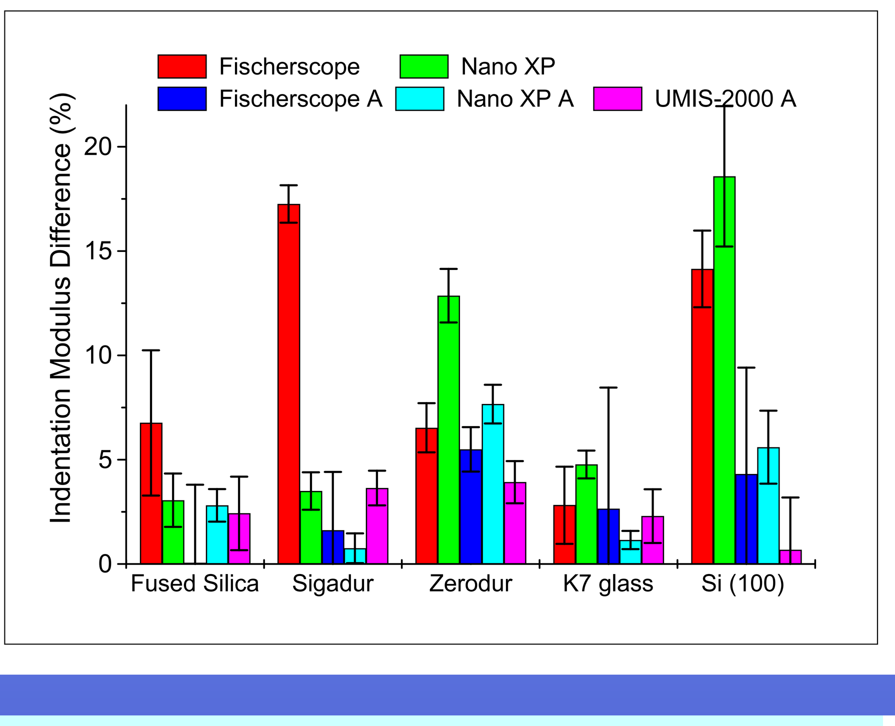


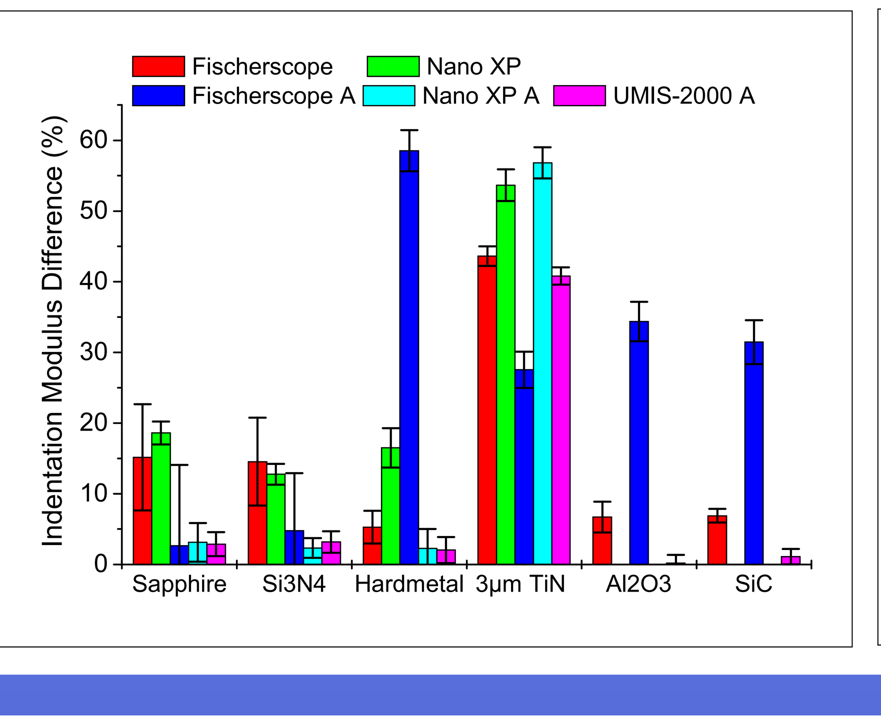


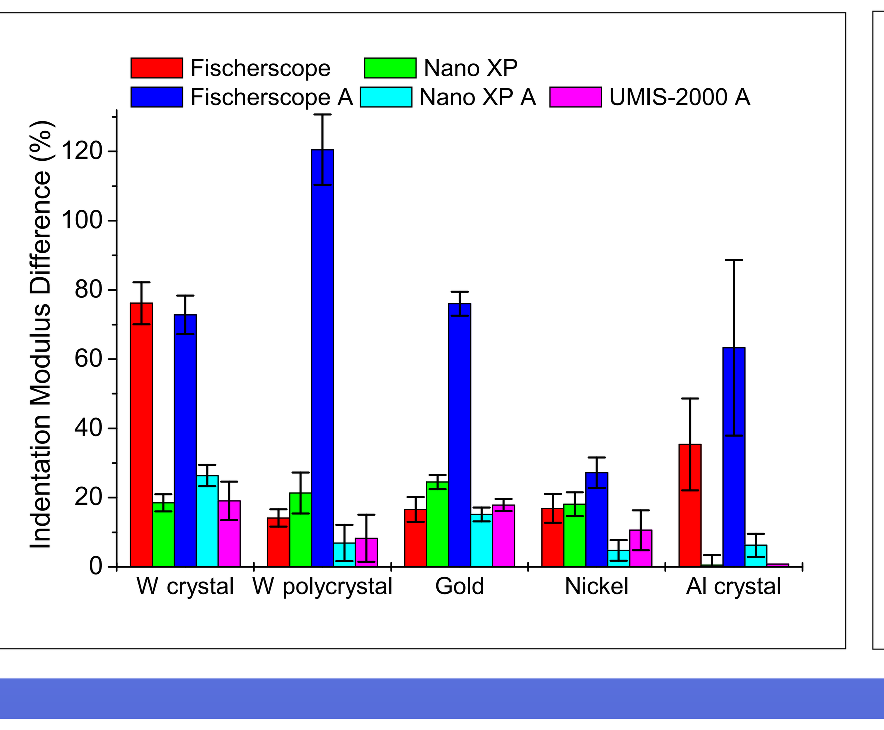


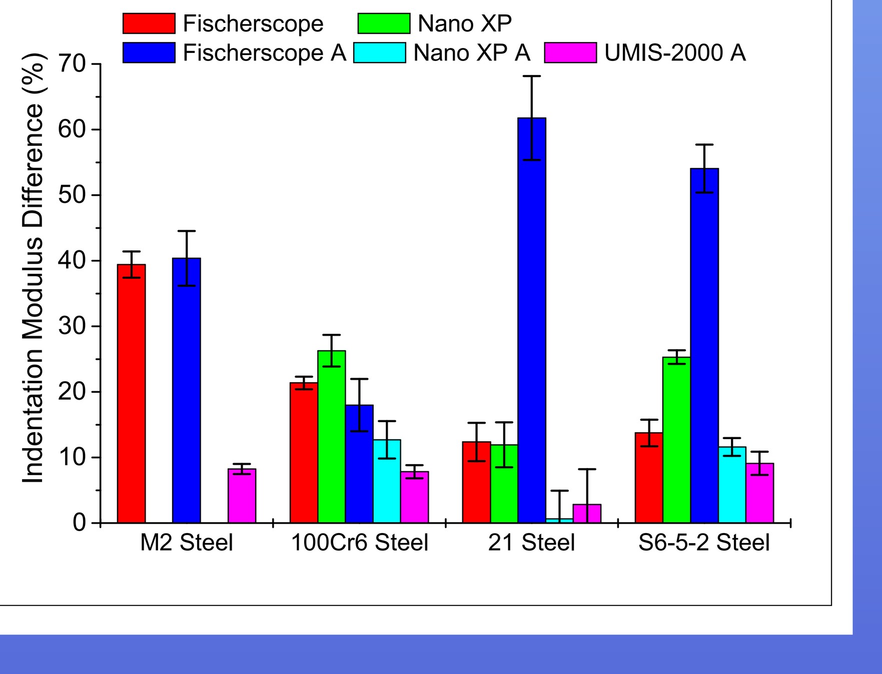


Young's modulus comparison (difference to table value)









Summary and conclusions

The conventional Vickers hardness overestimates the indentation area for materials with sink-in behaviour like used silica (cushion shape of indents). The indentation hardness underestimates the area for materials with pile-up behaviour like many metals. However with the newest contact mechanical corrections (Indent Analyser software) the hardness results of both methods agree better than 10% while the standard software shows a difference of more than 25 %. The modulus results of the Indent Analyser software deviate only about 6% from the reference values as average over all investigated materials. This confirms the correctness of the contact area calculation. The results for the standard analysis software are worse (see table). The large modulus difference for the Fischerscope can be related to a material dependent instrument compliance and problems with the displacement calibration. The example for a coated system (TiN) shows that it is impossible to get comparable hardness results with both methods if the indentation depth is more then about 10-30% of film thickness.

Instrument, Software	Mean difference Hardness	Mean difference Modulus
Fischerscope, original	29.43	18.01
Nanoindenter XP, original	25.48	16.48
Fischerscope, Indent Analyser	9.17	35.79
Nanoindenter XP, Indent Analyser	8.19	6.88
UMIS-2000, Indent Analyser	9.70	5.63

Mean difference as average of all materials except TiN

More details of this investigation will be published in a separate BAM report.

Contact: t.chudoba@asmec.de; michael.griepentrog@bam.de

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