

Mechanical Properties of Silicon Carbide Wafer Metal Coatings



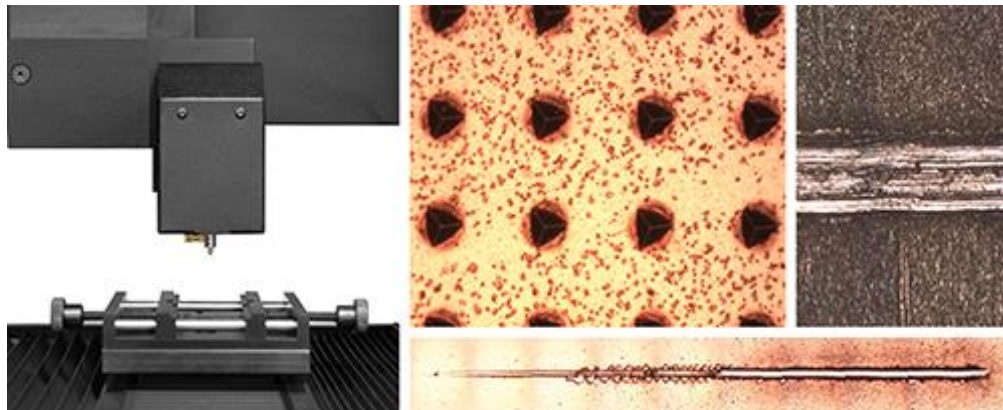
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INTRO

Single crystal silicon carbide (c-SiC) wafers are widely used in the production and manufacturing of microelectronic devices such as integrated circuits (IC) or photovoltaic (PV) cells. Most wafers are formed from highly pure single crystals and can range in size from 25.4 mm to 300 mm. The wafer acts as the substrate for the micro-devices that are fabricated in, and over, the wafer. Doping or ion implantation, photolithographic patterning, deposition of different materials, and etching are all examples of the many micro-fabrication process steps a wafer can go through.

IMPORTANCE OF MECHANICAL TESTING IN DETERMINING HARDNESS, ADHESION/SCRATCH RESISTANCE AND TRIBOLOGICAL PROPERTIES OF WAFER COATINGS

The fabrication process for microelectronic devices can have over 300 different processing steps and can take anywhere from six to eight weeks. During this process, the wafer substrate must be able to withstand the extreme conditions of manufacturing, since a failure at any step would result in the loss of time and money. The hardness, adhesion/scratch resistance and COF/wear rate of the wafer must meet certain requirements in order to survive the conditions imposed during the manufacturing and application process to insure a failure will not occur.



MEASUREMENT OBJECTIVE

In this application, the Nanovea Mechanical Testers Micro module is used to measure the hardness (GPa)/Young's Modulus (E), Adhesive/Cohesive Failures and COF/Wear Rate of coatings on silicon carbide wafers. The wafers have a $\sim 4.5 \mu\text{m}$ coating on top of a silicon carbide substrate. By determining the hardness and Young's Modulus of these coating the role the substrate plays in these properties can be examined. By determining the adhesive/cohesive resistance of the coatings, we will be able to see the force at which they begin to fail. Lastly, determining the COF and wear rate of the coatings will allow us to see the rate at which material is lost and their frictional properties.

TEST CONDITIONS AND PROCEDURE

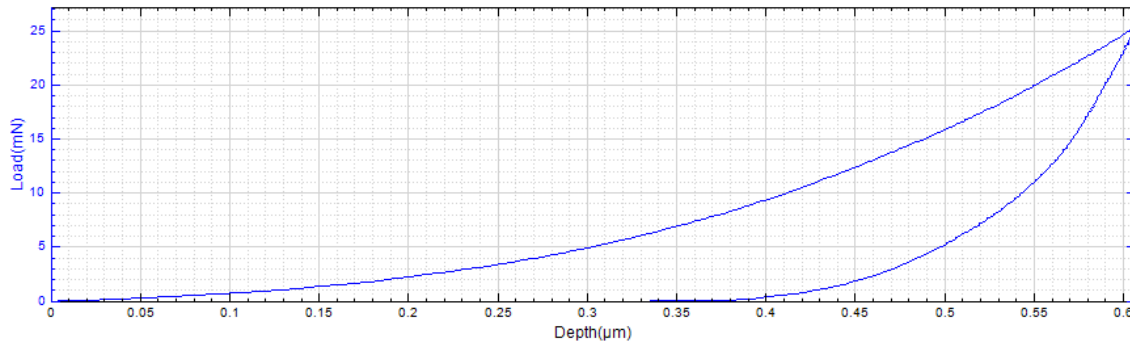
The following indentation parameters were used:

MicroIndentation Test Parameters	
Maximum Force (mN)	25
Loading Rate (mN/min)	50
Unloading Rate (mN/min)	50
Computation Method	ASTM E-2546 & Oliver & Pharr
Indenter Type	Berkovich

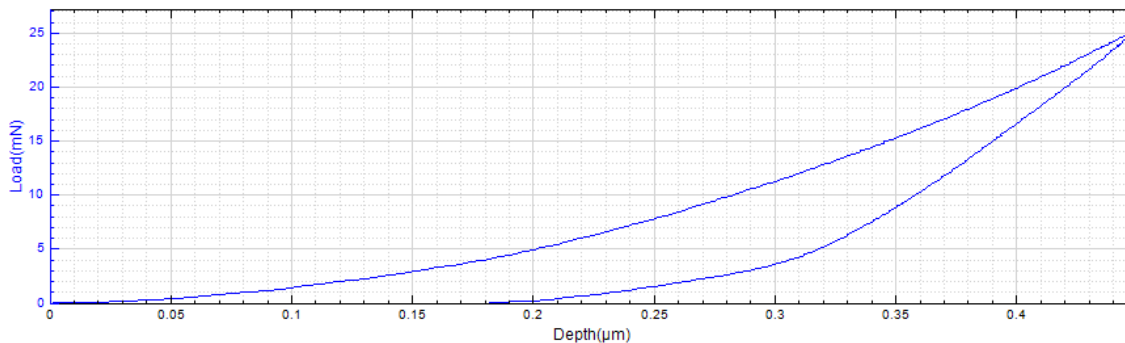
RESULTS:

Five indents were made per sample in order to calculate an average Vickers Hardness, Hardness (GPa) and Young's Modulus. The load vs depth curves that each indent made were analysed in order to assure appropriate initial point of contact and unloading curve slope. The data below clearly shows a higher average hardness for the Control coating versus the Au Alloy Coating and a higher Young's Modulus for the Au alloy coating than the Control coating.

Test	Au Alloy Coating			
	Hardness [Vickers]	Hardness [GPa]	Young's Modulus [GPa]	Max Depth [nm]
1	366	3.87	113.1	571
2	318	3.37	103.4	609
3	325	3.44	106.8	602
4	316	3.34	103.0	611
5	321	3.40	107.6	604
Average	329	3.48	106.8	599
Standard Deviation	21	0.22	4.1	16



Control Coating				
Test	Hardness [Vickers]	Hardness [GPa]	Young's Modulus [GPa]	Max Depth [nm]
1	854	9.04	87.8	448
2	798	8.44	92.9	450
3	821	8.69	91.4	448
4	877	9.28	94.6	437
5	845	8.94	90.7	446
Average	839	8.88	91.5	446
Standard Deviation	30	0.32	2.5	5



DISCUSSION:

In conclusion, the Nanovea Mechanical Tester's Micro module demonstrates reproducibility and precise indentation at low levels. The controlled and closely monitored environment allows the measurement of hardness to be used as a quantitative value for comparing a variety of samples. This test also shows that it can measure other characteristics, such as Young's modulus and maximum depth. Here we have shown the ability to control the specific load being applied to test the thin coatings on top of silica carbide wafers.

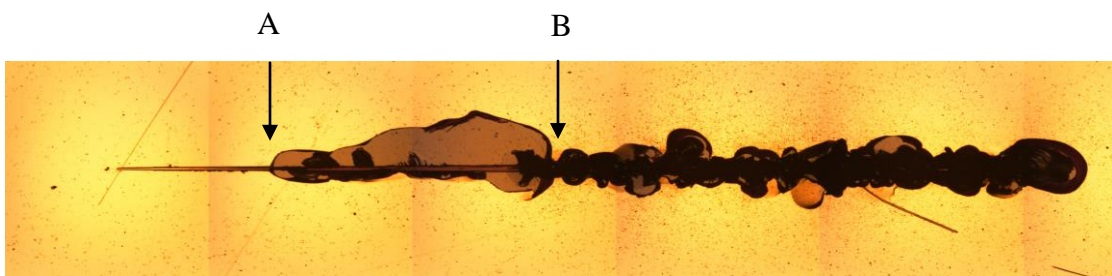
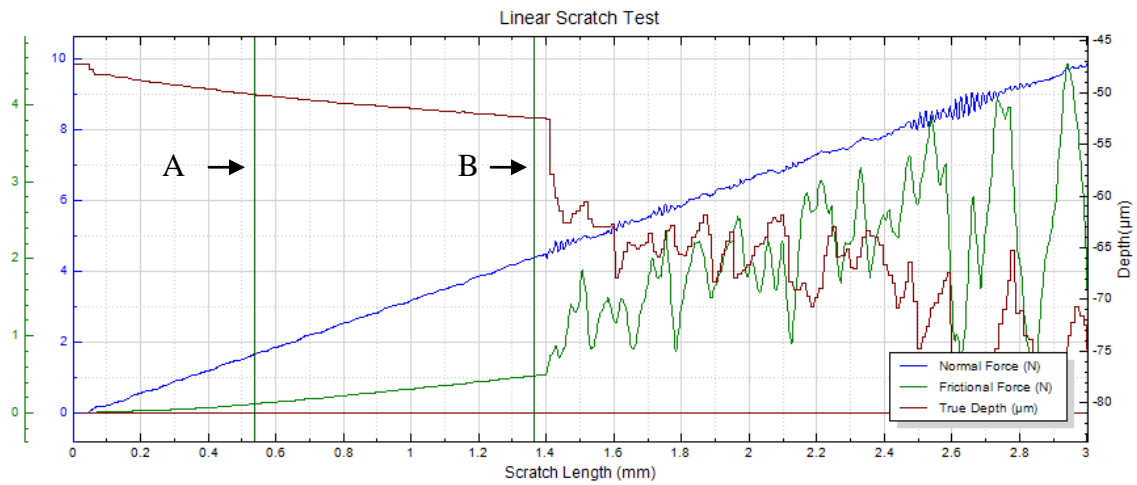
TEST CONDITIONS AND PROCEDURE

Microscratch Test Parameters	
Load type	Progressive
Initial Load (N)	0.1
Final Load (N)	10
Loading rate (N/min)	20
Scratch Length (mm)	3
Scratching speed (mm/min)	6
Indenter geometry	90° cone
Indenter material (tip)	Diamond
Indenter tip radius (μm)	20

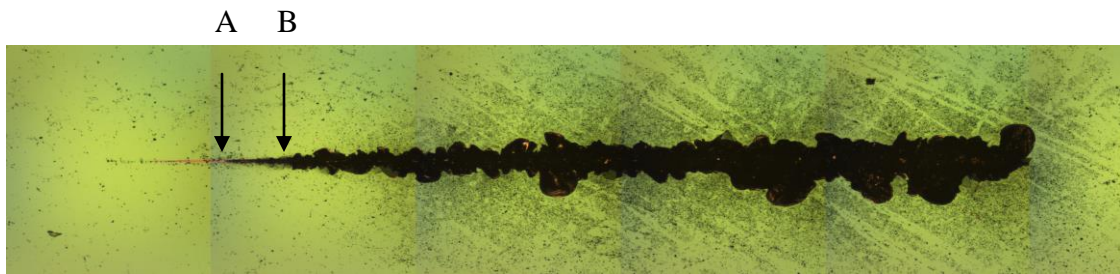
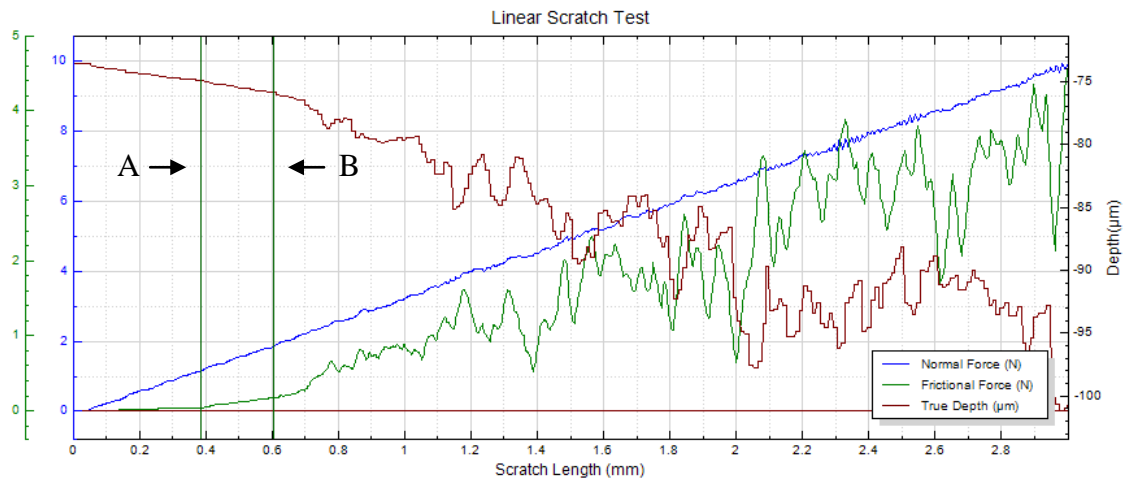
RESULTS:

The cohesive failure (A) and adhesive failure (B) of the coatings are reported as the load at which these phenomena occur. The data shows that the Au alloy coating has a higher cohesive and adhesive strength than the control coating. Three scratches were performed for each sample and a graph containing the load, depth and frictional force are shown as well as a full-length image for one of the scratches to visually show the failures. It is important to mention that the repeatability of the scratches can vary due to the uniformity of the coating and substrate.

Au Alloy Coating		
Scratch	Adhesive Coating Failure (N)	Cohesive Substrate Failure (N)
1	1.86	4.258
2	1.666	4.399
3	2.214	4.455
Average	1.913	4.371
Standard Deviation	0.278	0.102



Scratch	Control Coating	
	Adhesive Coating Failure (N)	Cohesive Substrate Failure (N)
1	1.15	1.860
2	1.171	1.851
3	1.154	1.793
Average	1.158	1.835
Standard Deviation	0.011	0.036



DISCUSSION:

In conclusion, The Nanovea Mechanical Testers ability to apply a wide range of loads allows the user to produce repeatable low to high load scratches on a material. This ability is valuable for the wafer industry because manufacturers of these wafers can see at which loads the coating will fail.

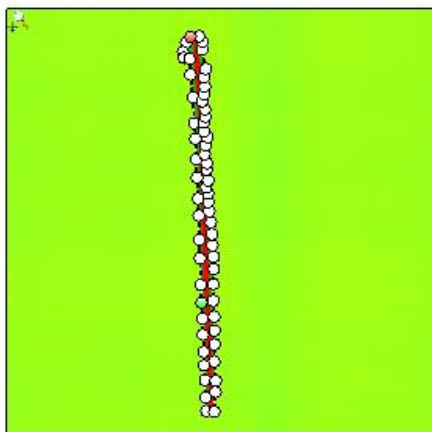
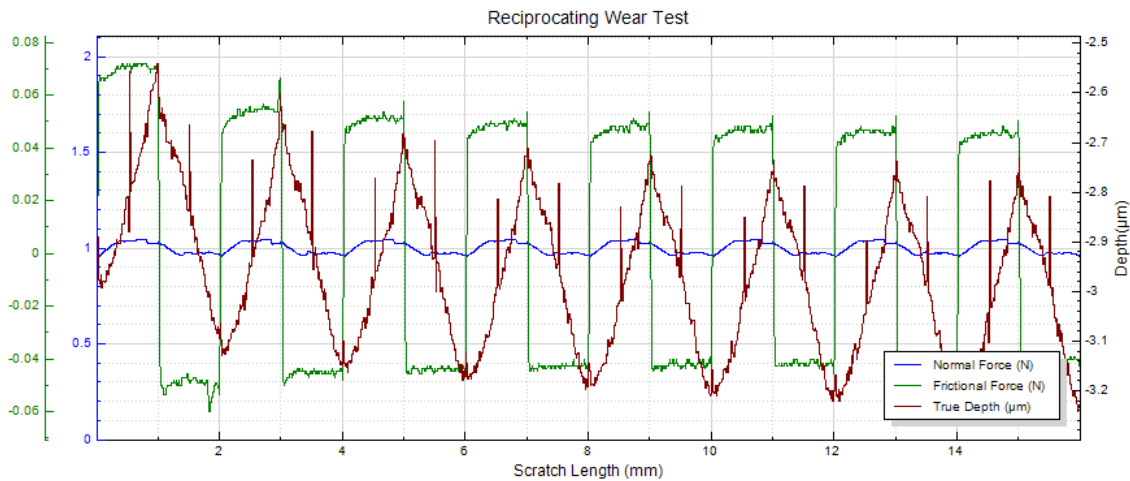
TEST CONDITIONS AND PROCEDURE

Microwear Test Parameters	
Load type	Constant
Load (N)	1
Scratch Length (mm)	1
Scratching speed (mm/min)	8
Total Distance traveled (mm)	16
Indenter geometry	90° cone
Indenter material (tip)	Diamond
Indenter tip radius (μm)	20

RESULTS:

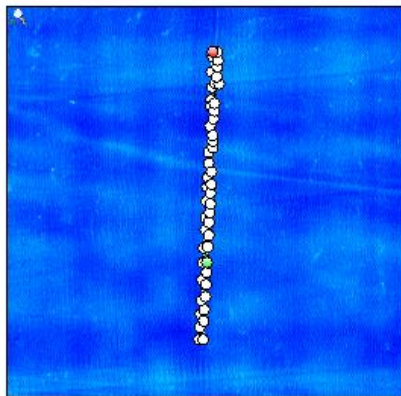
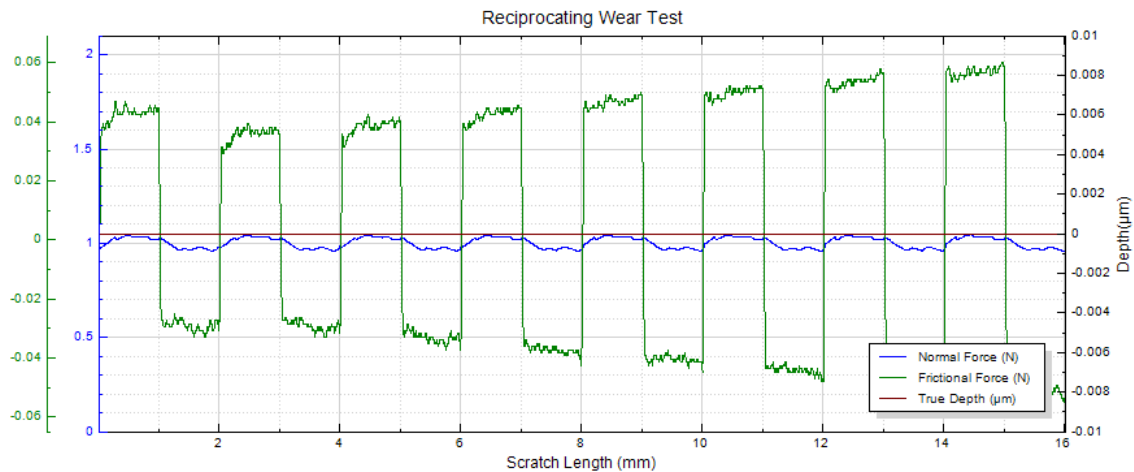
The following data sets represent the tribology study and tests performed on the Au and Control coating with the Nanovea Mechanical Tester. Linear reciprocating scratch tests were performed on both coatings with the same testing parameters in order to compare the COF and wear rate of each. The wear rate for Au alloy coating was greater than the wear rate for the control coating. However, the average COF was the same for both coatings. The wear rate was calculated by scanning the post worn area with the Nanovea 3D profilometer and calculating the volume loss.

Sample	Max COF	Min COF	Average COF	Wear Rate x10 ⁻⁹ (mm ³ /Nm)
Au Alloy Coating	0.0659	0.0397	0.0470	335.938



Parameters	Unit	Hole
Surface	mm ²	0.01339
Volume	μm ³	5375
Max. depth/height	μm	4.038
Mean depth/height	μm	0.4013

Sample	Max COF	Min COF	Average COF	Wear Rate $\times 10^{-9}$ (mm ³ /Nm)
Control Coating	0.0578	0.0277	0.0422	0.411



Parameters	Unit	Hble
Surface	mm ²	0.0003115
Volume	nm ³	6550359155
Max. depth/height	nm	74.04
Mean depth/height	nm	21.03

DISCUSSION:

The Nanovea Mechanical Testers micro module is able to not only apply progressive loads but constant loads as well in order to perform tribological studies on thin wafer coatings. By using the same testing parameters, the user is able to compare various materials in order to see how they will perform. The sensitivity that the instrument has allows us to see even the smallest COF values and wear rates.

In conclusion, it was shown that the Nanovea Mechanical Testers micro module with its unmatched load range (0.003 to 20N and 0.03 to 200N) can fully test coatings using nanoindentation to micro scratch and wear levels. Many other tests could be performed such as controlled fracture toughness and yield strength measurements among many others all on a single system.

To learn more about [Nanovea Mechanical Tester](#) or [Lab Services](#).