TRIBOLOGICAL/STICTION BEHAVIOR OF ULTRATHIN QUASICRYSTAL FILMS DEPOSITED ON SILICON DEVOTED FOR MICRO/NANOTECHNOLOGICAL APPLICATIONS

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- *INTRODUCTION*
- *PREPARATION OF QUASICRYSTALLINE COATINGS*
- *NANOTRIBOLOGICAL CHARACTERIZATION*
  - AFM BASED MICROTRIBOMETER
  - FRICTION AND STICKING
  - WETTABILITY
- *CONCLUSIONS AND OUTLOOK*

WARSAW UNIVERSITY OF TECHNOLOGY

TU WIEN

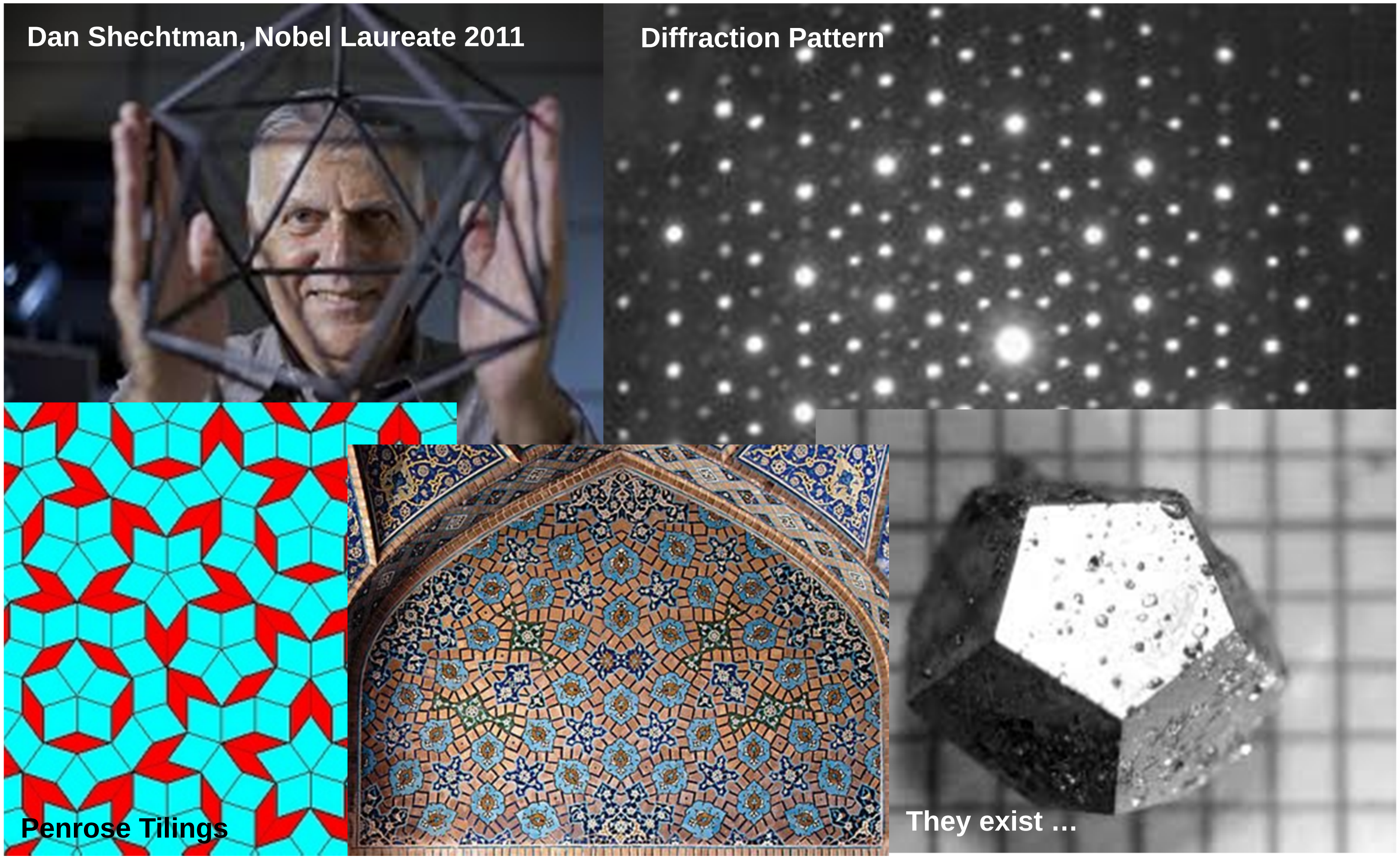
Introduction

- **The materials used in micro/nanotechnological applications like that used for fabrication of sliding components in MEMS/NEMS devices usually demonstrate poor tribological properties and in particular sticking inclinations.**
- **Special coatings are useful which can perform tribological functions as well as can perform antisticking function.**
- **Such interesting properties :relatively low surface energy and good mechanical resistance against deformations demonstrate quasicrystals e.g. complex metallic alloys (CMA)**
- **The low surface energy surfaces are interesting in sliding contacts in the applications in particular in vacuum conditions e.g. in space.**

Introduction

- The ultrathin (with thicknesses in nanometer range) CMA films PVD deposited on single crystal silicon have been studied in the clean-room environment with the use of the Atomic Force Microscope (AFM) based microtribometer to identify their tribological and adhesive behaviors.
- The additional wettability studies supported the AFM tests. The results of these extensive studies will be presented and discussed in the report.

QUASICRYSTALS



PROPERTIES OF QUASICRYSTALS

- ***Relatively High Hardness***
- ***High Youngs's Modulus***
- ***Low adhesion and sticking forces***
- ***Low surface energy***
- ***High wear resistance***
- ***Chemical inertness***
- ***Low electrical and thermal conductivity***
- ***Coefficients of thermal expansion like common metals***

This list makes quasicrystals (QC) extermely interesting for tribological applications. Low surface energy and antisticking properties favor applications related to MEMS/NEMS and Nanoimprint Lithography (NIL).

DRAWBACKS OF QUASICRYSTALS

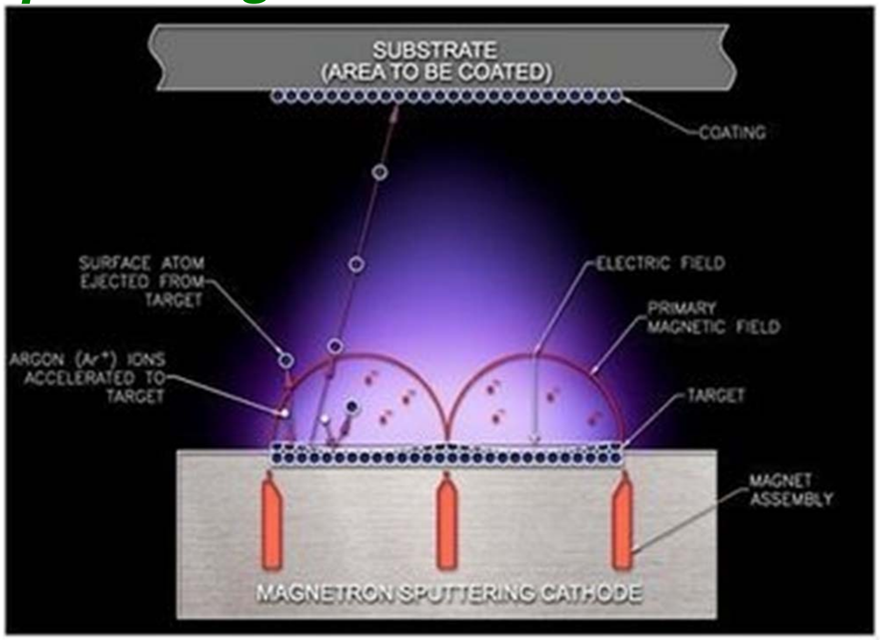
- ***High brittleness***
- ***Complex composition***

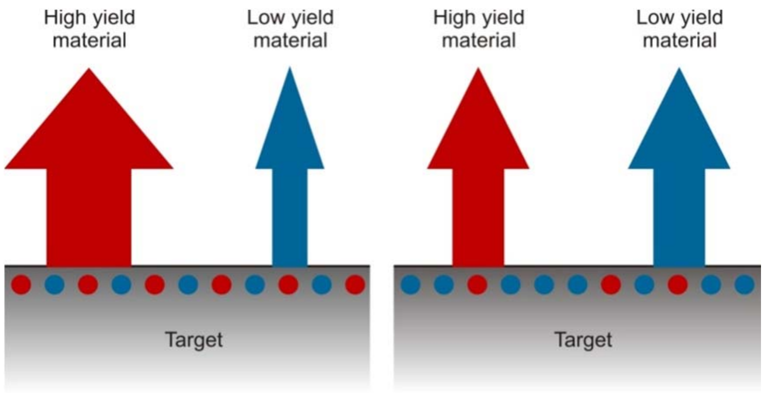
Issues of brittleness and composition may be attacked by depositing thin films of quasicrystalline material e.g. :

$Al_{59}Cu_{25.5}Fe_{12.5}$

QUASICRYSTALLINE COATINGS

Deposition by PVD Magnetron Sputtering

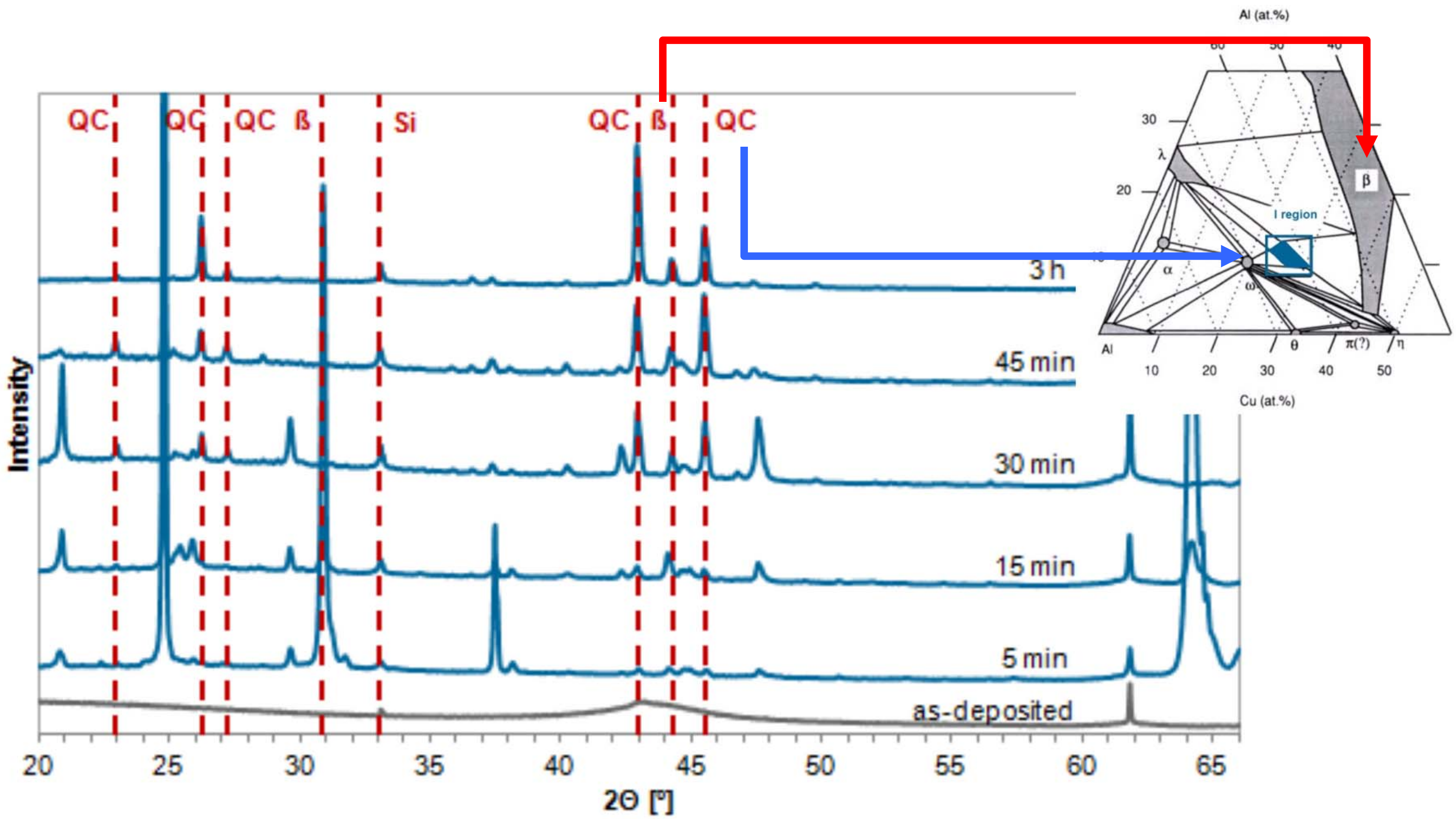




The composition of sputtered coatings is equal to the composition of the source even for multimaterial sources due to the direct transfer of the coating material from the solid phase to the vapor phase.

CRYSTALLINE STRUCTURE

Annealing a coating deposited at room temperature at 600°C produces a composite of QC and β phase.



NANOTRIBOLOGICAL CHARACHERIZATION

Investigated coatings:	***AlCuFeB***
Substrate Material:	***Si***
Thickness:	***500 nm***
Phase composition:	***40% QC $Al_{59}Cu_{25.5}Fe_{12.5}$***
	60 % $Al_{50}Cu_{40}Fe_{10}$ (ß phase)
Varied deposition parameters:	***deposition temperature, sputter pressure, bias voltage***

Nanotribological methods:

AFM based microtribometer: surface topography, friction , adhesion (pull-off force), wettability , nanoindentation, nanoscratch and nanowear studies

Tests on CMA coatings

- **TUW Si coated samples.   Identified properties:**

By AFM studies: surface topography, friction, pull-off force (adhesive properties), nano-wear

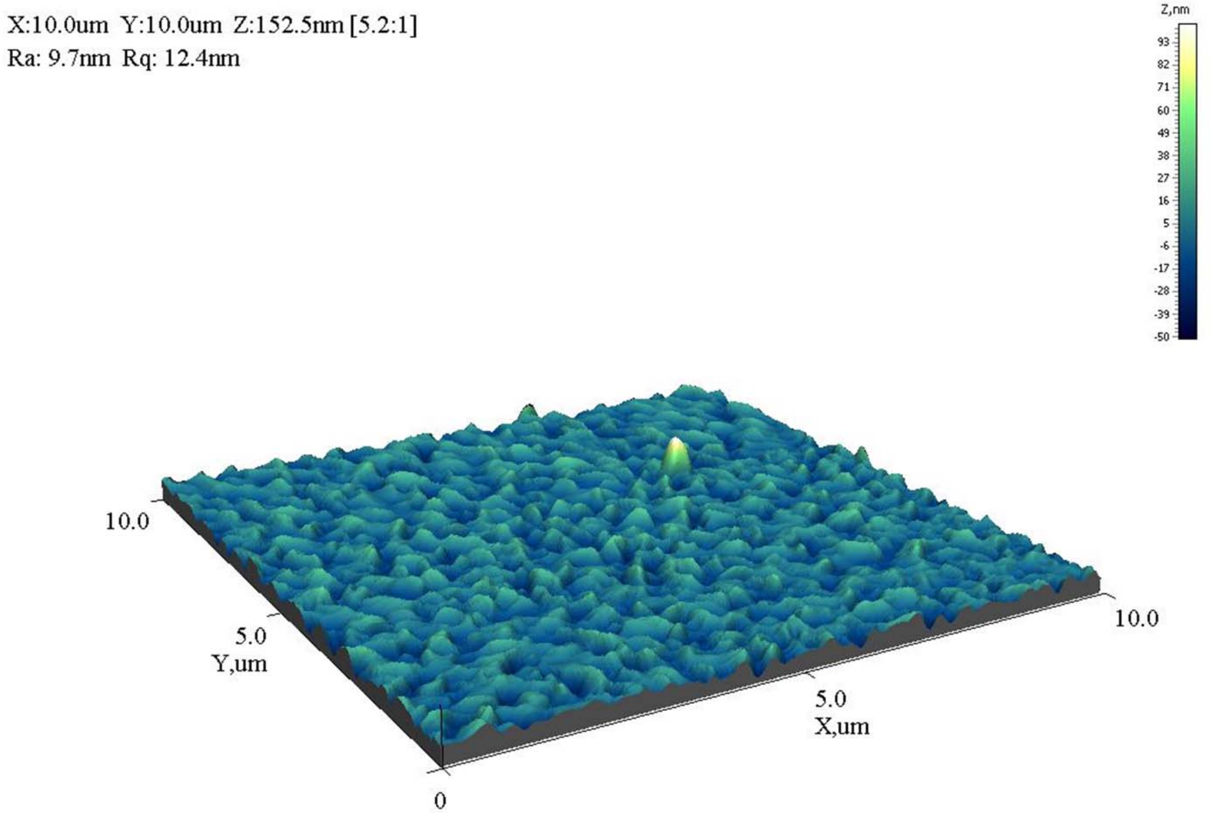
By nanoindentation: hardness, elasticity modulus, nano-scratch (nanoindenter with lateral force transducer)

By wettability tests: contact angles, surface energy (polar, dispersive component): two liquids used: water, diiodomethane

Tests performed in clean room lab:

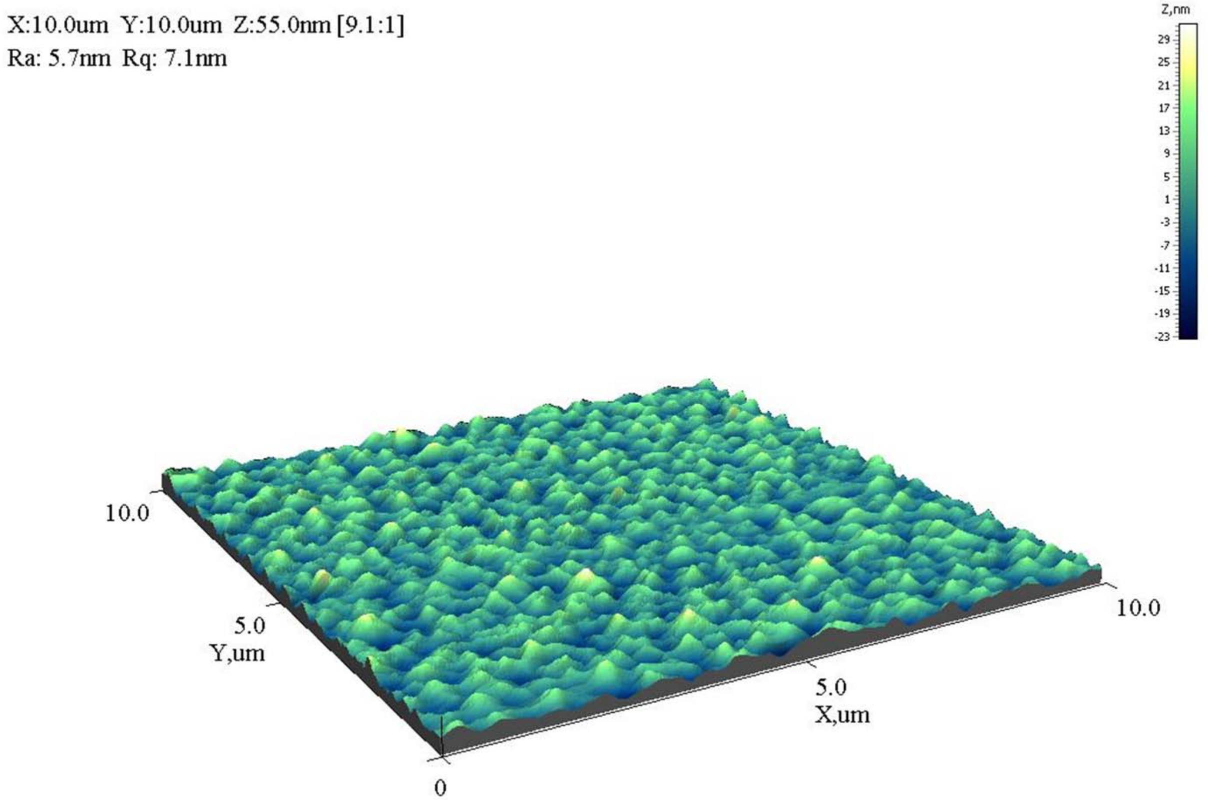
- **temperature 20°C ±1°C   humidity 20%±5%**
- **atmospheric pressure ,   air atmosphere**

CMA_TUW_110



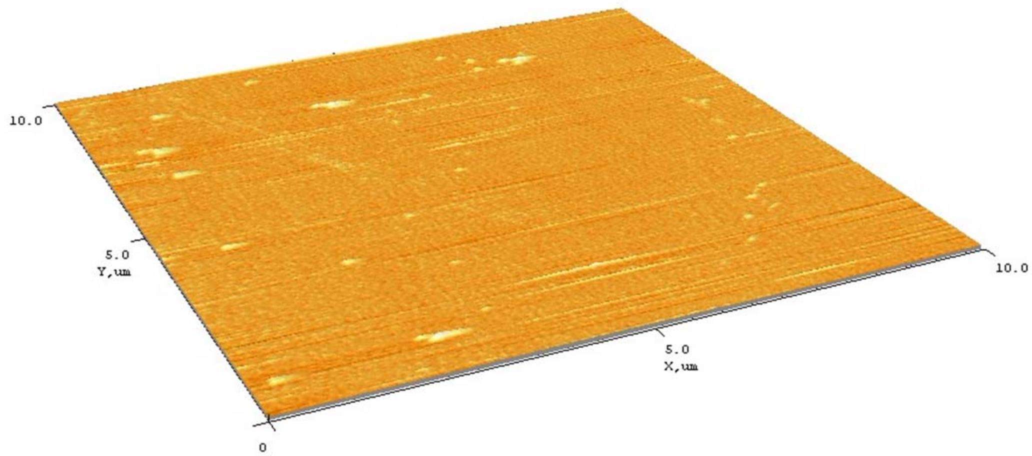
X:10.0um Y:10.0um Z:152.5nm [5.2:1]
Ra: 9.7nm Rq: 12.4nm
Z,nm
93
82
71
60
49
38
27
16
5
-6
-17
-28
-39
-50
10.0
5.0
Y,um
0
5.0
X,um
10.0

CMA_TUW_120



X:10.0um Y:10.0um Z:55.0nm [9.1:1]
Ra: 5.7nm Rq: 7.1nm
Z,nm
29
25
21
17
13
9
5
1
-3
-7
-11
-15
-19
-23
10.0
5.0
Y,um
0
5.0
X,um
10.0

Silicon wafer



Sample	Si
R_a parameter	0.2 nm
R_q parameter	0.3 nm

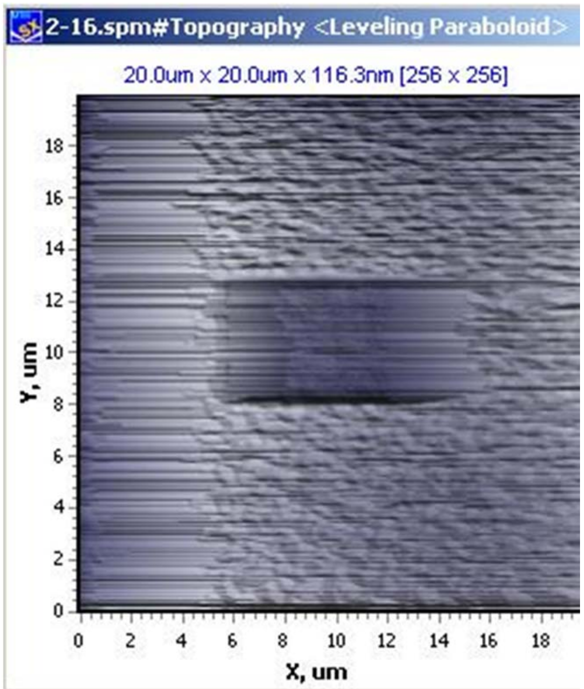
Surface topography

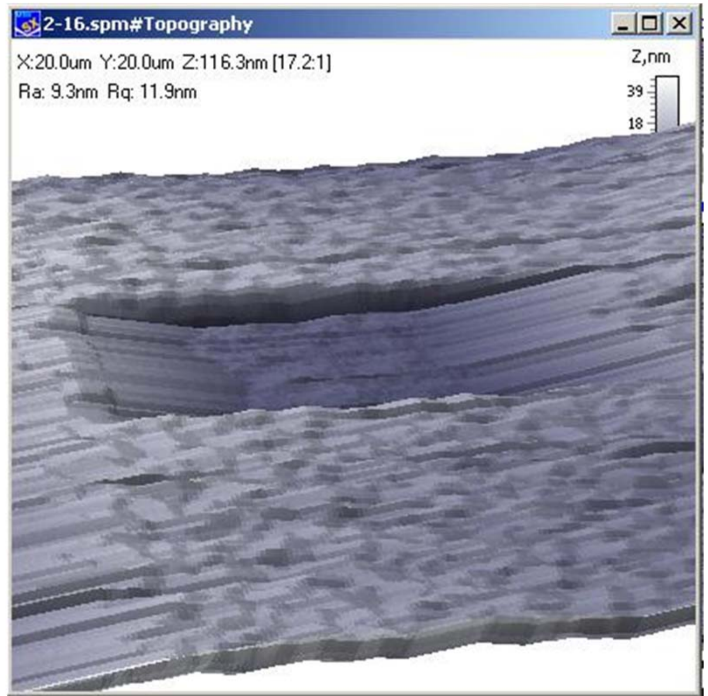
Sample	Ra avg [nm]	Rq avg [nm]
CMA_TUW_109	7,0	10,5
CMA_TUW_110	10,1	12,7
CMA_TUW_111	5,2	8,0
CMA_TUW_112	5,6	7,3
CMA_TUW_113	5,9	9,6
CMA_TUW_114	3,3	6,1
CMA_TUW_115	6,3	8,9
CMA_TUW_116	6,9	9,6
CMA_TUW_117	4,9	6,7
CMA_TUW_118	8,6	10,8
CMA_TUW_119	5,6	7,5
CMA_TUW_120	5,9	7,5
Si	[illegible]	[illegible]

Pull-off force (AFM sticking tests)

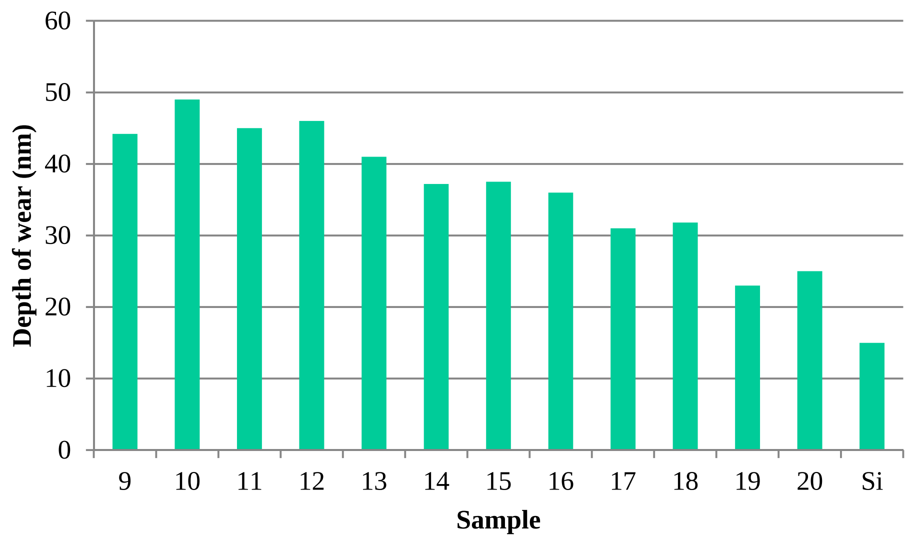
	Probe with glass ball		Probe with glass ball coated PMMA	
	Pull-off force [µN]	Standard deviation	Pull-off force [µN]	Standard deviation
CMA_TUW_109	34	23	2,7	1,1
CMA_TUW_110	150	105	3,2	2,4
CMA_TUW_111	81	52	7,2	4,6
CMA_TUW_112	46	66	8,3	4,7
CMA_TUW_113	1,6	5,2	4,8	2,7
CMA_TUW_114	0,8	2,9	6,3	5,8
CMA_TUW_115	1,6	3,9	3,3	1,8
CMA_TUW_116	8,4	12	5,8	4
CMA_TUW_117	2,6	7,3	6,4	2,8
CMA_TUW_118	2	7,5	3,8	2,4
CMA_TUW_119	1,1	4	11	5,5
CMA_TUW_120	1,1	5	5,4	2,1
silicon	84	74	N/A	N/A

Nano-wear


2-16.spm#Topography <Leveling Paraboloid>
20.0um x 20.0um x 116.3nm [256 x 256]
Y, um
X, um
0
2
4
6
8
10
12
14
16
18

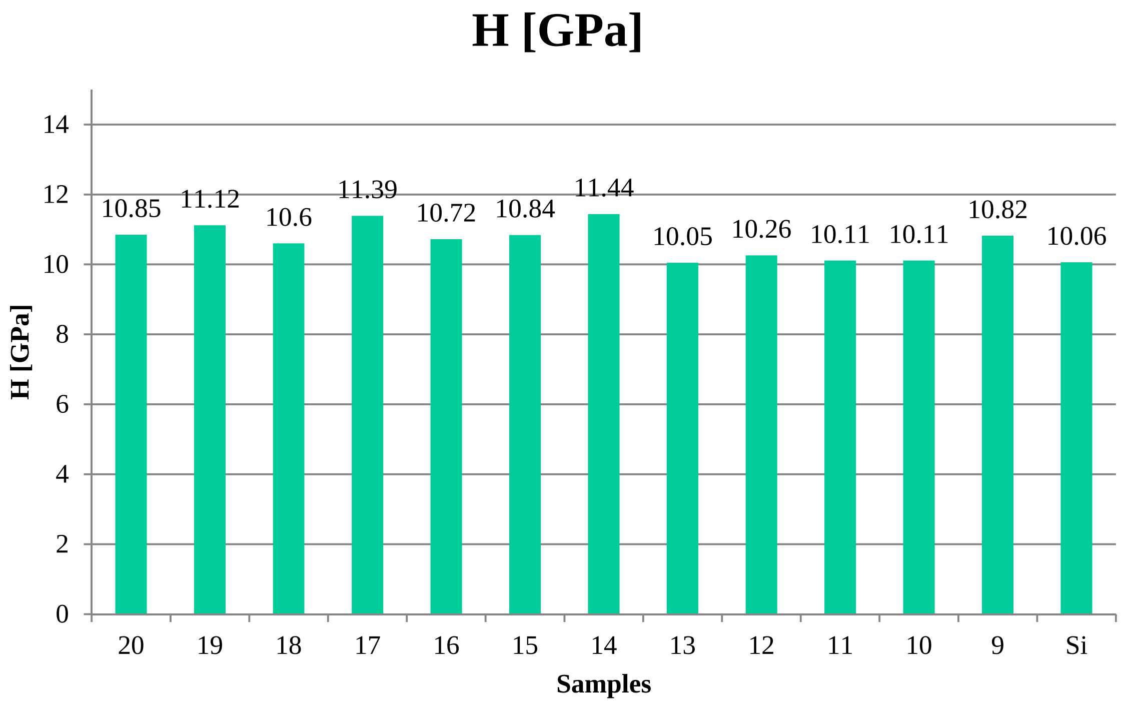

2-16.spm#Topography
X:20.0um Y:20.0um Z:116.3nm [17.2:1]
Ra: 9.3nm Rq: 11.9nm
Z,nm
39
18

Nano-wear TUW Comparison

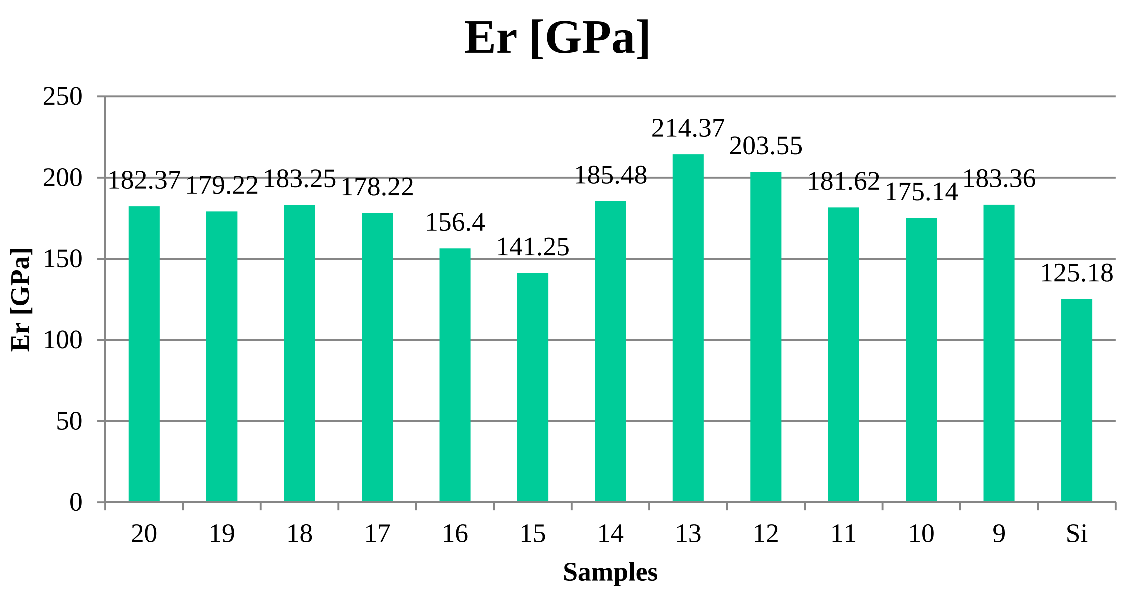


Sampl e:	9	10	11	12	13	14	15	16	17	18	19	20	Si
Depth of wear [nm]	44,19	49	45	46	41	37,2	37,5	36	31	31,8	23	25	15

NanoindentationTUW Comparison



Nanoindentation TUW Comparison

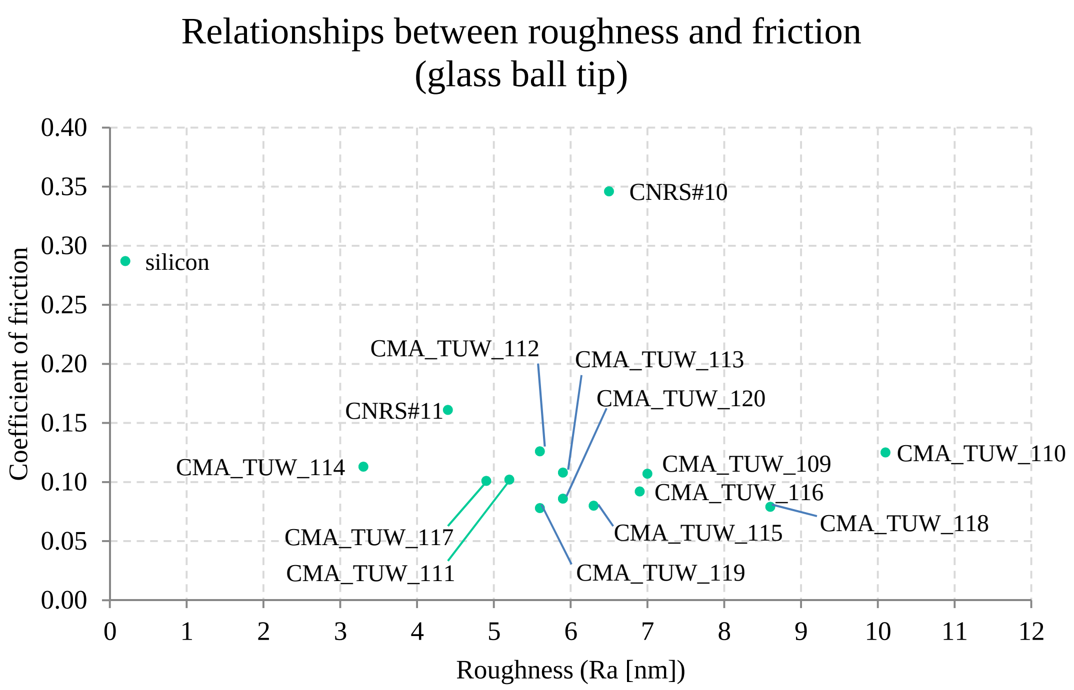


	20	19	18	17	16	15	14	13	12	11	10	9	Si
Er [GPa]	182,37	179,22	183,25	178,22	156,4	141,25	185,48	214,37	203,55	181,62	175,14	183,36	125,18
H [GPa]	10,85	11,12	10,60	11,39	10,72	10,84	11,44	10,05	10,26	10,11	10,11	10,82	10,06

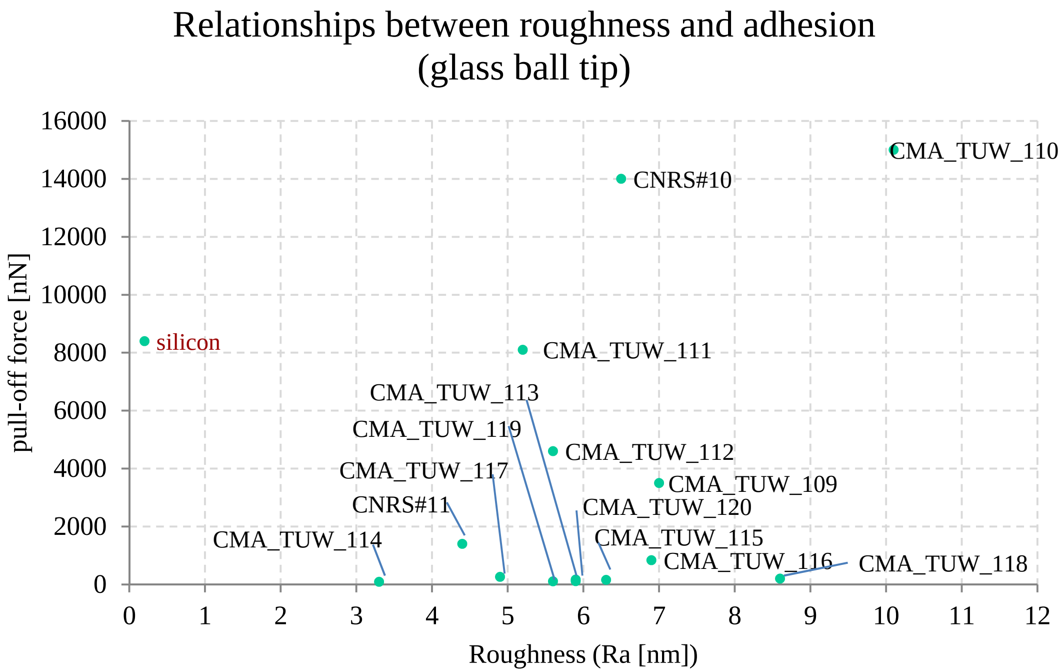
AFM BASED MICROTRIBOMETER

Probe for friction / pull-off force measurements	
type	IMiF, beryllium bronze
tip	Glass ball 500µm
length [µm] ± 10	2040
width [µm] ± 5	410
thickness [µm] ± 2m	60
force constant [N/m]] ± 5	110

Velocity of sliding was 17µm/s
Load 300 µN



STICKING/ADHESION (PULL-OFF FORCE)

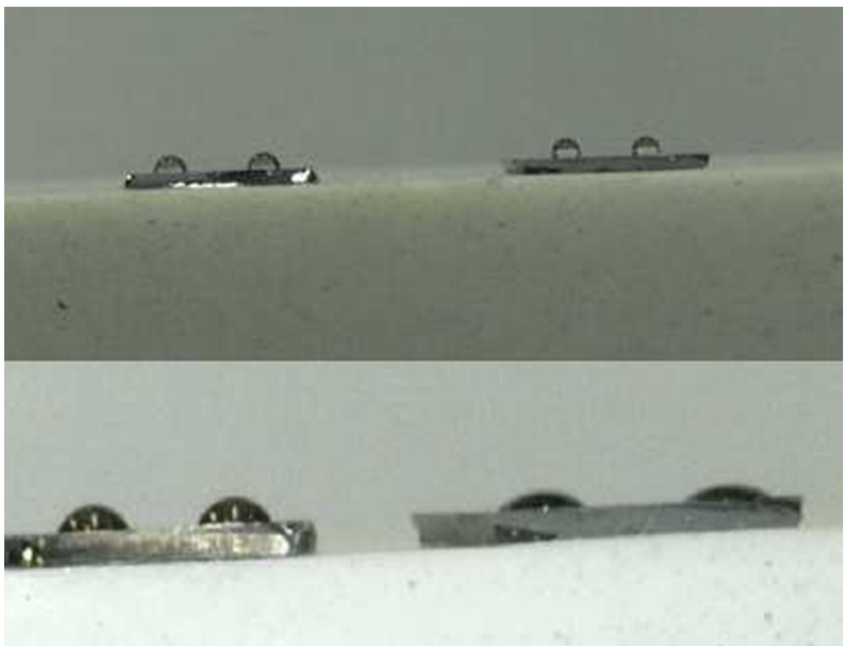


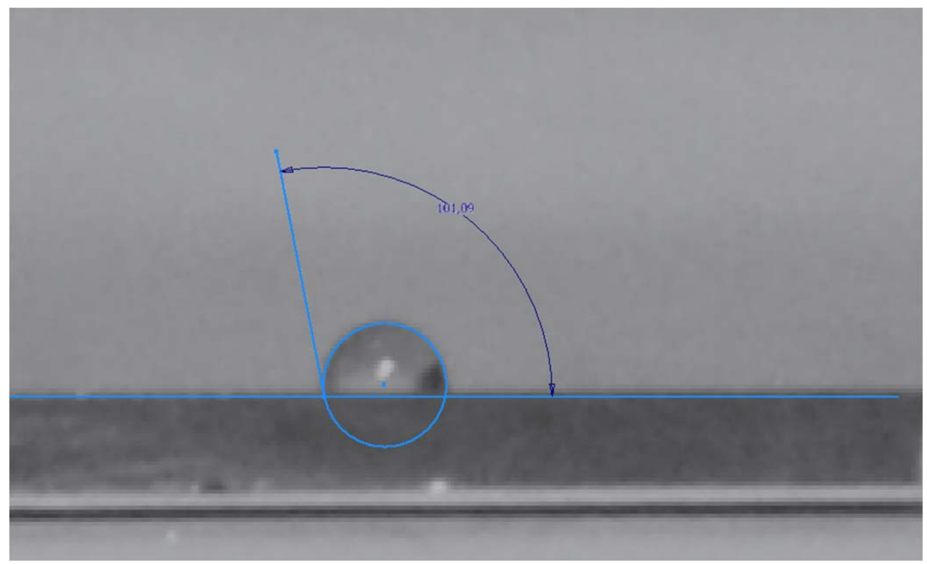
Wettability studies

Droplets were placed on coatings with use of the automatic pipette, their volume was about 0.2 nl of water and

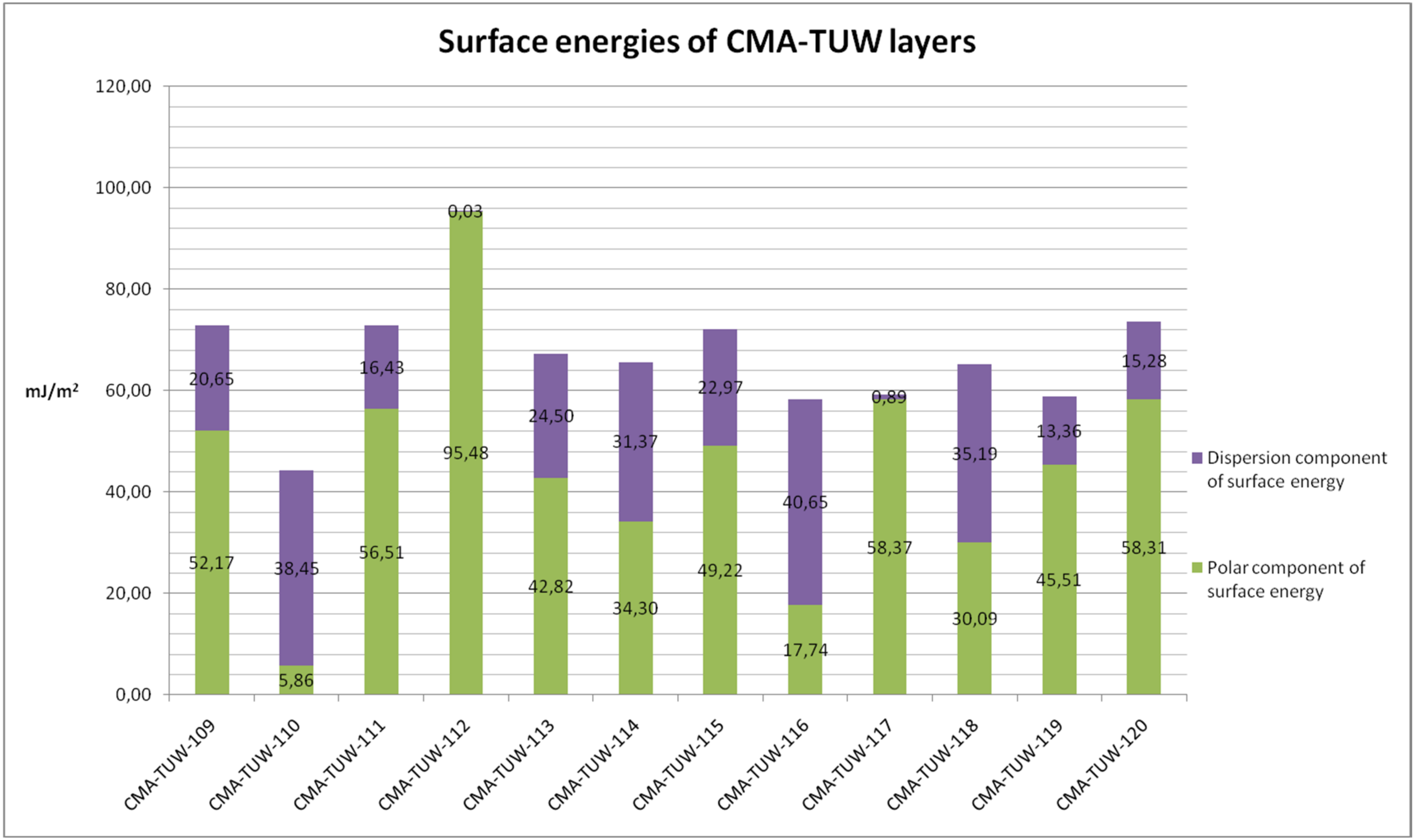
diiodomethane.

Owens-Wendt method was applied to estimate surface free energy

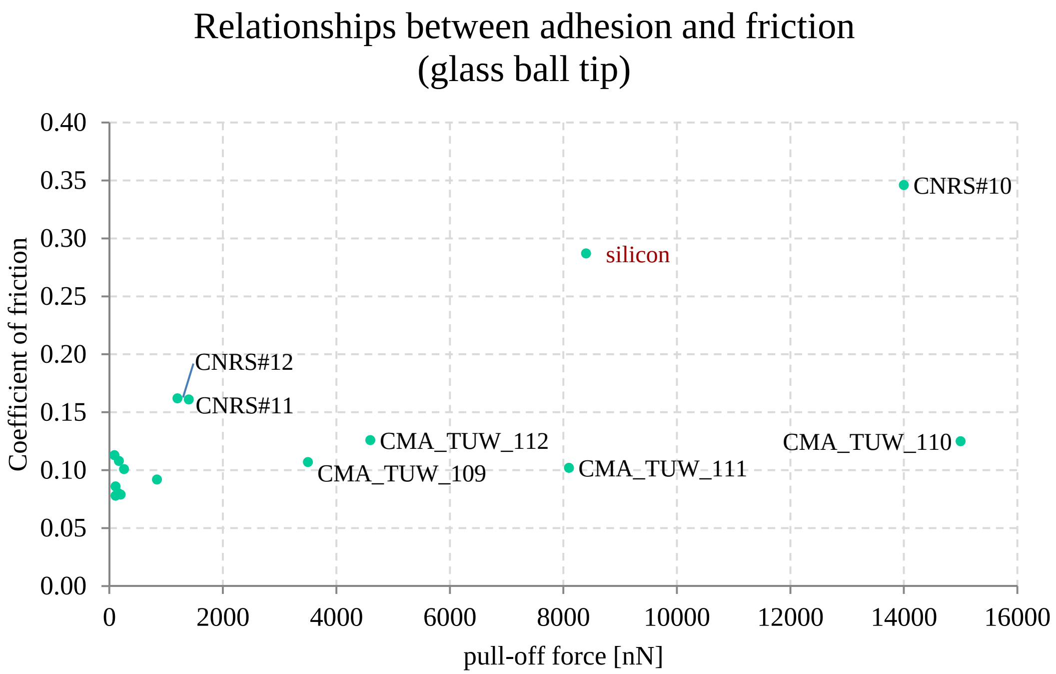




WETTABILITY



SUMMARY OF NANOTRIBOLOGICAL RESULTS



FINAL SUMMARY

- ***Production of QC coatings***

  PVD magnetron sputtering allows for the production of QC coatings with complex composition. Deposition parameters can be used to optimize crystallinity and phase composition.

- ***Nanotribology***

  Friction and adhesive /stiction properties can be optimized by the surface roughness : both friction and adhesion /stiction play very important role in the MEMS/NEMS and NIL application of coatings.

- ***Conformal coatings on MEMS/NEMS and NIL molds***

  Multi step or multi source processes may serve as tools to produce highly conformal coatings on MEMS/NEMS components as well as e.g. NIL molds with complex geometry and high aspect ratios.

ACKNOWLEDGEMENTS

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