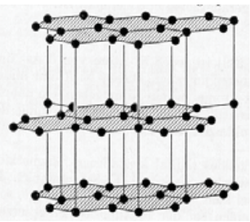
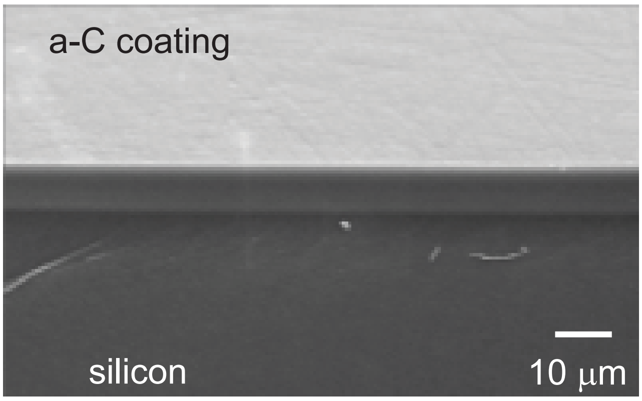
Karlsruhe Institute of Technology

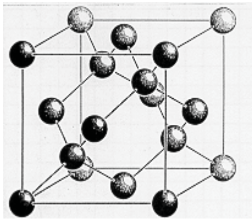
Amorphe Kohlenstoffschichten und deren Eignung als biofunktionale Oberflächen

Michael Stüber

INSTITUTE FOR APPLIED MATERIALS – APPLIED MATERIALS PHYSICS (IAM-AWP), DEPARTMENT OF COMPOSITES AND THIN FILMS







Outline

- ➢ relevance of amorphous and diamondlike carbon coatings
- ➢ DLC coatings – some fundamental aspects
- ➢ DLC coatings – from R&D level to industrial production
- ➢ DLC coatings – future challenges

Applications in medicine and pharmacy …


knee-prosthesis
(IonBond AG)


urology: catheter
(OptiMed Medizinische
Instrumente GmbH)

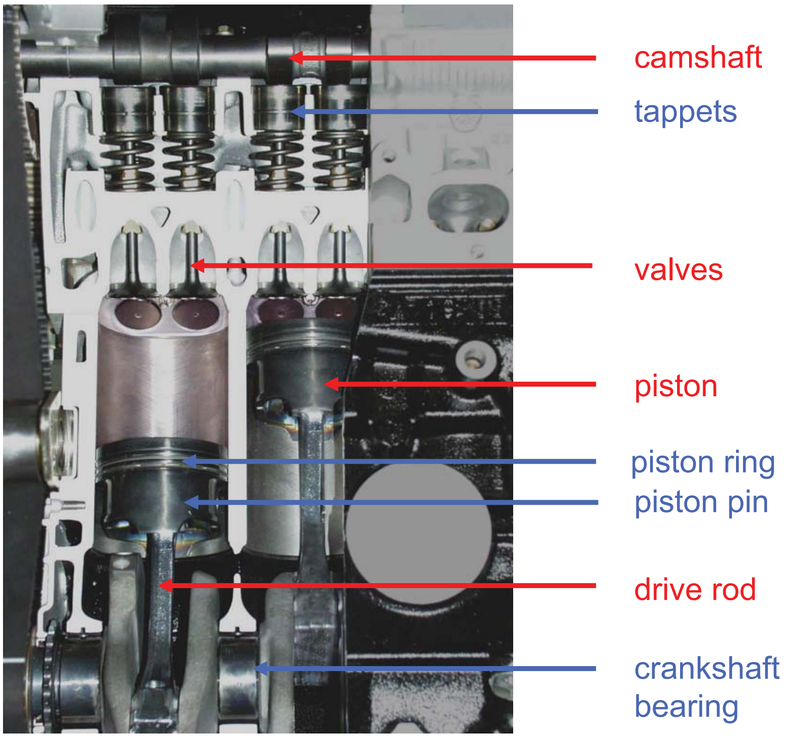

one way syringe
(Sulzer Metaplas)


chirurgical instruments
(Plascotec GmbH)


cardiovascular valve
(St.Jude Medical)


tabletting tool
(Notter GmbH)

… applications in engineering



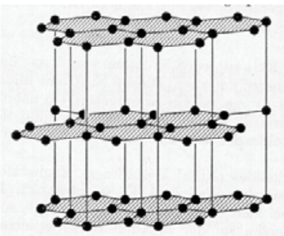
G. van der Kolk, IonBond AG, PSE 2006


Fraunhofer IST, Braunschweig


Rübig GmbH

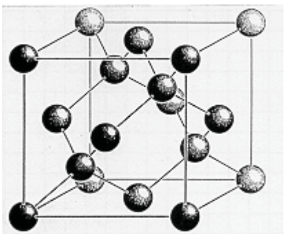
Carbon materials – bulk and thin films

graphite



sp^2 bonds

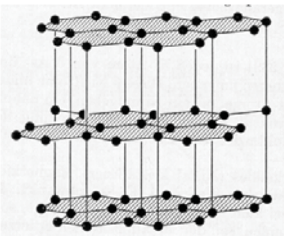
diamond



sp^3 bonds

Carbon materials – bulk and thin films

graphite



sp^2 bonds

a-C, a-C:H

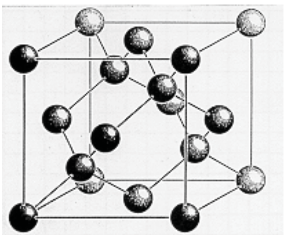
ta-C, ta-C:H

carbon-based coatings

a-C:H:X
X = Si, O, N, F, B

CVD diamond

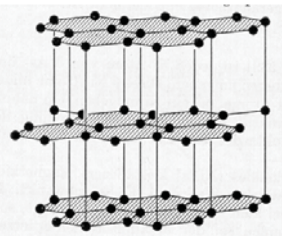
diamond



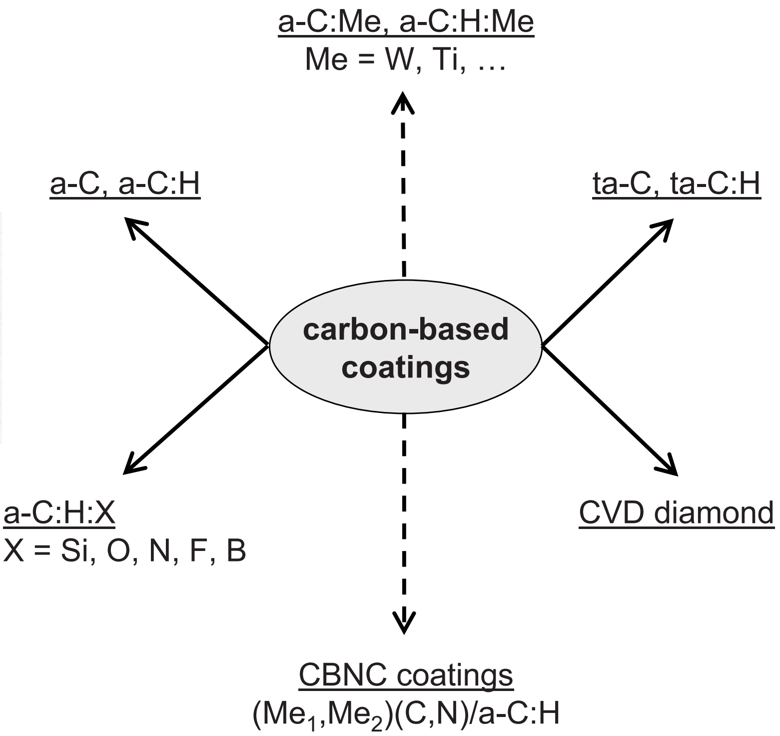
sp^3 bonds

Carbon materials – bulk and thin films

graphite



sp^2 bonds



a-C:Me, a-C:H:Me
Me = W, Ti, …

a-C, a-C:H

ta-C, ta-C:H

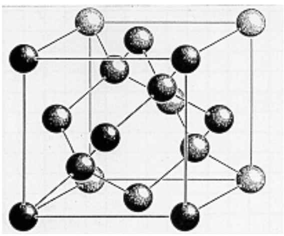
carbon-based coatings

a-C:H:X
X = Si, O, N, F, B

CVD diamond

CBNC coatings
$(Me_1,Me_2)(C,N)/a\text{-}C:H$

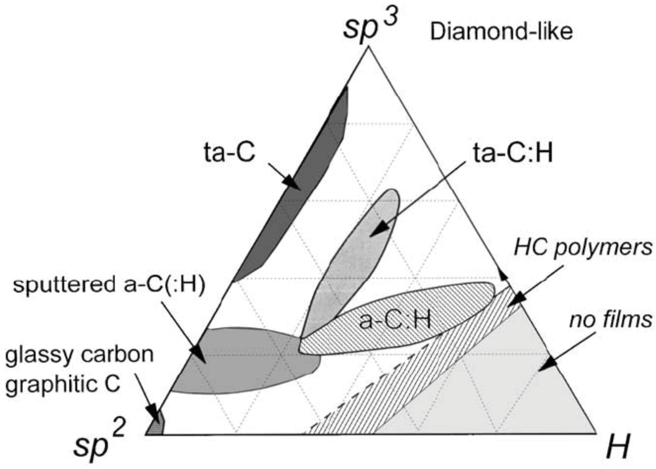
diamond



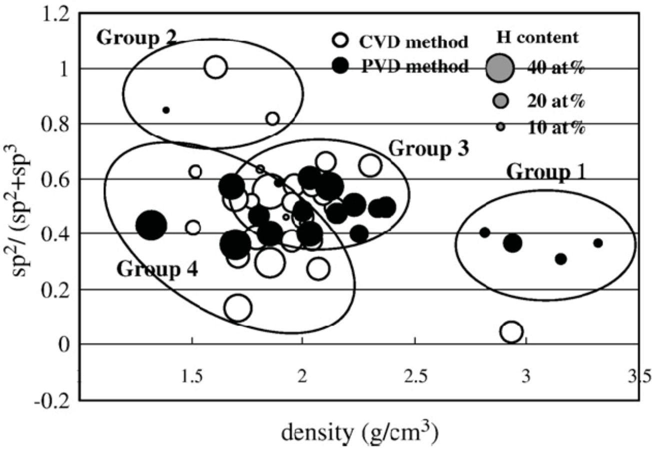
sp^3 bonds

Classification of amorphous carbon coatings

Ternary phase diagram of bonding states in amorphous carbon and carbon-hydrogen materials



Variations of the sp^2/(sp^2+sp^3) ratio versus the density of DLC films



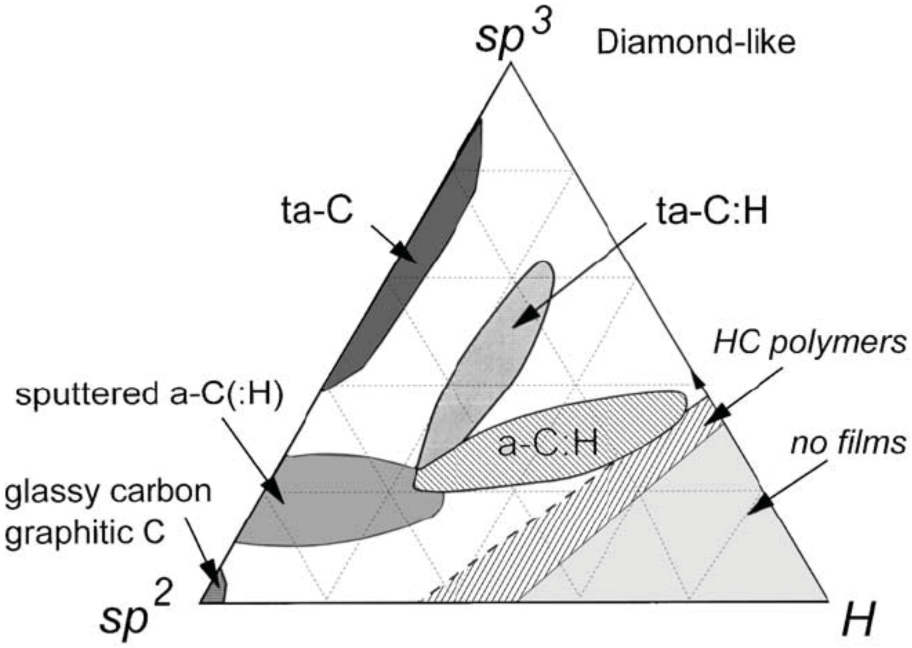
J.Robertson, Mat. Sci. Eng. R 37 (2002) 129

A.C.Ferrari, J.Robertson, Phys. Rev. B 61 (2000) 14095

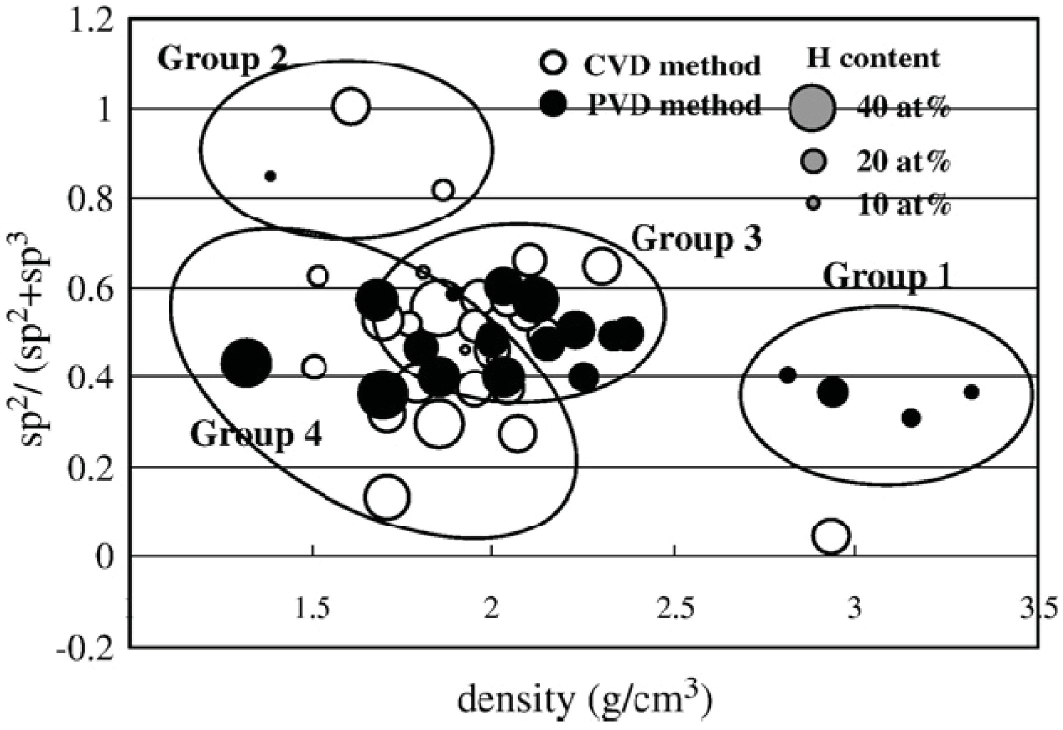
W.Jacob, W.Möller, Appl. Phys. Lett. 63 (1993) 1771

A.Saikubo et al., Diam. Rel. Mat. 17 (2008) 1743

Classification of amorphous carbon coatings

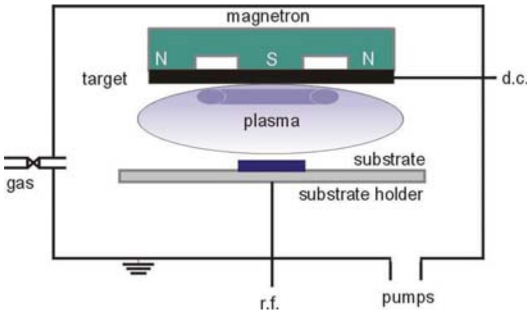


Classification of amorphous carbon coatings



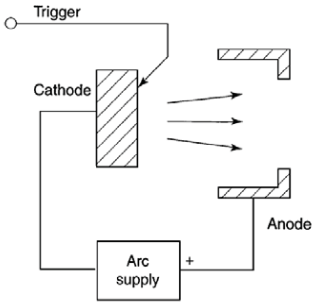
Synthesis of amorphous carbon coatings

magnetron sputtering



- non-equilibrium process
- low temperature
- no ions
- low deposition rate
- low particle energies

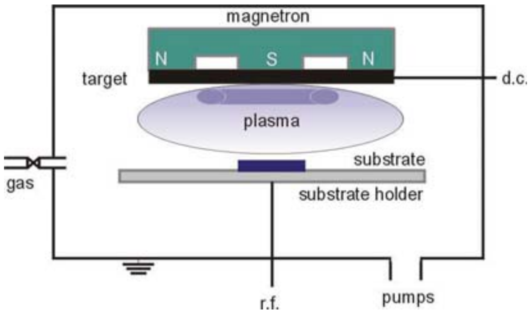
cathodic arc evaporation



- non-equilibrium process
- low temperature
- 100% ions
- high deposition rate
- high particle energies

Synthesis of amorphous carbon coatings

magnetron sputtering



- non-equilibrium process
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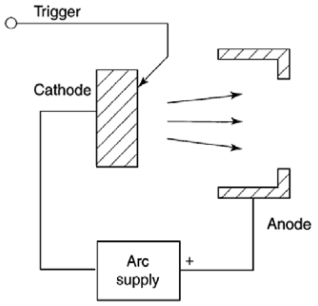
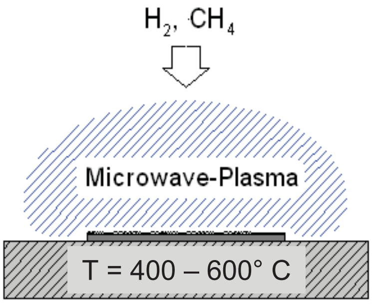
cathodic arc evaporation



- non-equilibrium process
- low temperature
- 100% ions
- high deposition rate
- high particle energies

plasma assisted CVD



- equilibrium process
- higher temperature
- molecules, radicals
- high deposition rate
- various particle energies

DLC synthesis – materials science point of view

DLC = amorphous carbon material with a significant fraction of sp^3 bonds

A.C.Ferrari, J.Robertson, Phys. Rev. B 61 (2000) 14095

DLC synthesis – materials science point of view

DLC = amorphous carbon material with a significant fraction of sp^3 bonds

A.C.Ferrari, J.Robertson, Phys. Rev. B 61 (2000) 14095

gas pressure, gas flow
cathode power densities
substrate temperature
substrate bias

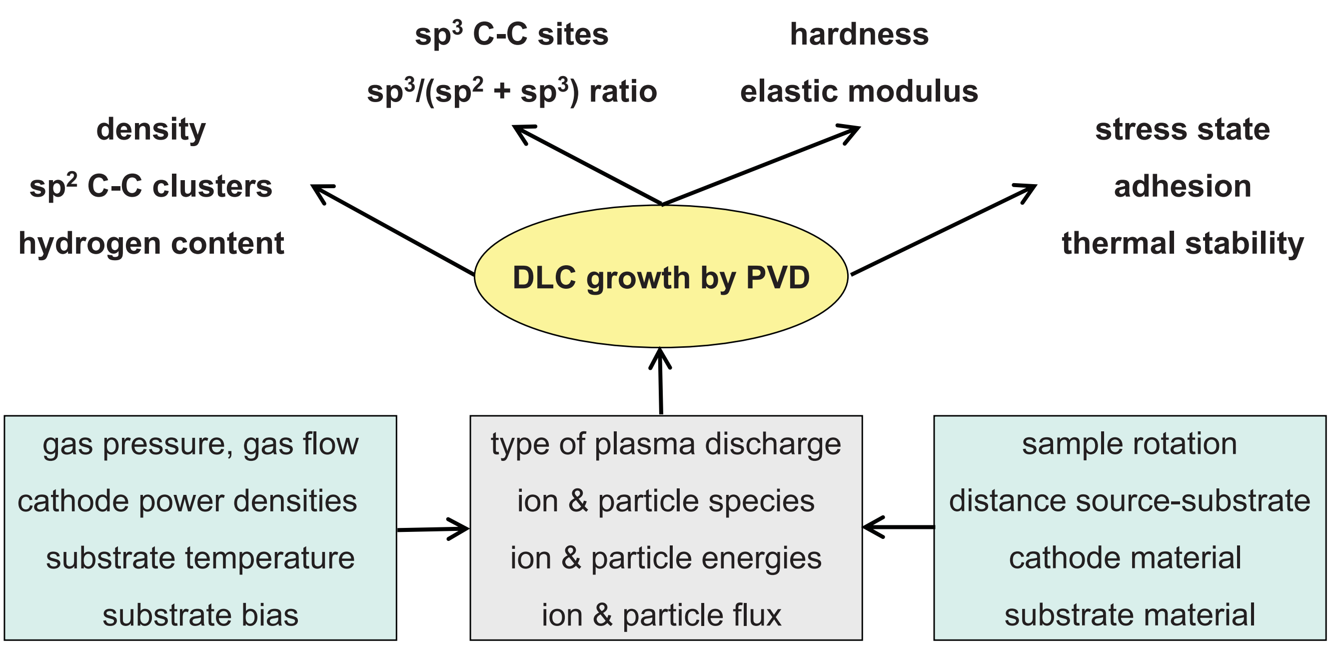
sample rotation
distance source-substrate
cathode material
substrate material

plasma deposition control for DLC growth by PVD

DLC synthesis – materials science point of view

DLC = amorphous carbon material with a significant fraction of sp^3 bonds

A.C.Ferrari, J.Robertson, Phys. Rev. B 61 (2000) 14095



sp^3 C-C sites

$sp^3/(sp^2 + sp^3)$ ratio

hardness

elastic modulus

density

sp^2 C-C clusters

hydrogen content

stress state

adhesion

thermal stability

DLC growth by PVD

gas pressure, gas flow
cathode power densities
substrate temperature
substrate bias

type of plasma discharge
ion & particle species
ion & particle energies
ion & particle flux

sample rotation
distance source-substrate
cathode material
substrate material

plasma deposition control for DLC growth by PVD

Scale-up of magnetron sputtering processes

laboratory scale
Leybold Z 550
targets < 150 mm

production scale
Hauzer HTC 625/Metaplas MZR 304/RF
targets: ca. 400 mm x 125 mm

Aspects of DLC synthesis at production scale

demands on
DLC technology

Aspects of DLC synthesis at production scale

Functionality & Performance

hardness – toughness
thermal & chemical stability
wear resistance
friction properties
multi-purpose coatings

demands on
DLC technology

Coating design

ultrathin – thick coatings
adhesion – stress management
interface engineering
Smooth, dense structures
amorphous – columnar growth

Aspects of DLC synthesis at production scale

demands on DLC technology

Functionality & Performance
hardness – toughness
thermal & chemical stability
wear resistance
friction properties
multi-purpose coatings

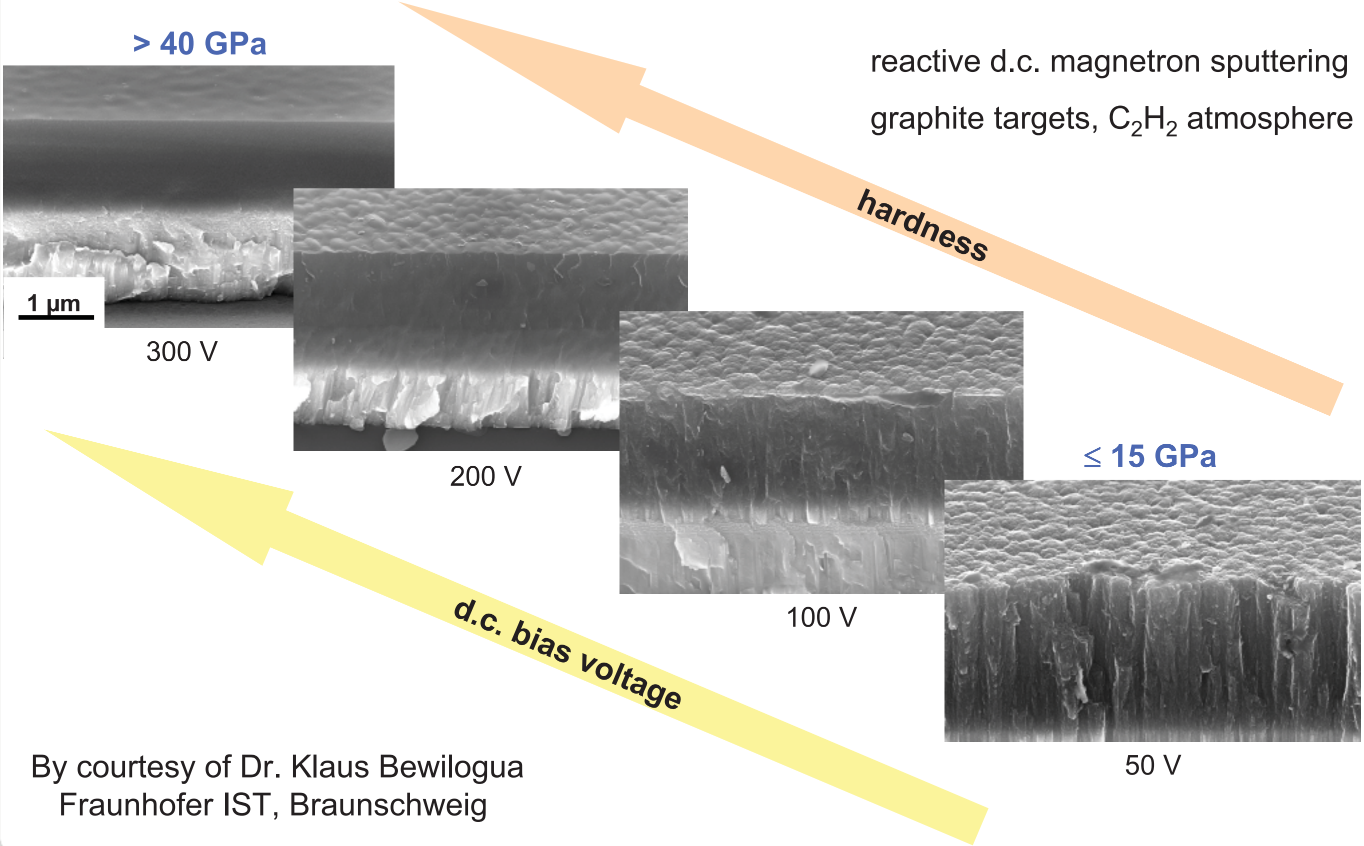
Production technology
process stability & reliability
processing costs
high volume deposition
high DLC growth rates
coating quality

Coating design
ultrathin – thick coatings
adhesion – stress management
interface engineering
Smooth, dense structures
amorphous – columnar growth

Technology development
high density plasma processes
low temperature deposition
multi-capability coating systems
hybrid technologies
pulsed methods (HIPIMS)

Structure and properties of C-DLC coatings

reactive d.c. magnetron sputtering
graphite targets, C_2H_2 atmosphere

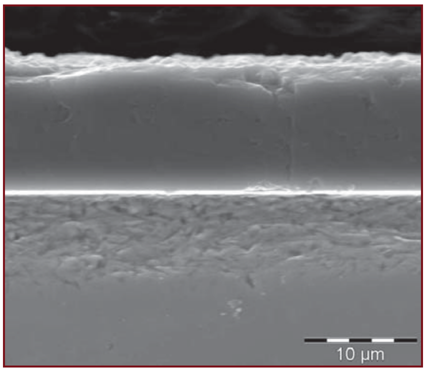


By courtesy of Dr. Klaus Bewilogua
Fraunhofer IST, Braunschweig

Diamor® - superhard carbon films by Laser-Arc deposition

physical / chemical properties

composition	nearly 100% carbon, < 1 at.-% H
density	2.4 – 3.2 g/cm^3
electr. resistivity	10^3 – 10^6 Wcm
refraction index	2.5 (at 700 nm wave length)
chem. resistance	inert (not against oxidising media and iron metals at elevated temp.)



amorphous ta-C structure

sp^3 (C-C) dominated

mechanical / tribological properties

Young´s modulus	400 – 650 GPa
hardness	40 – 65 GPa
coefficient of friction	0.10 – 0.15 (against steel under dry sliding conditions)

Laser-Arco® and **Diamor**® are copyrights of the
Fraunhofer Gesellschaft e.V

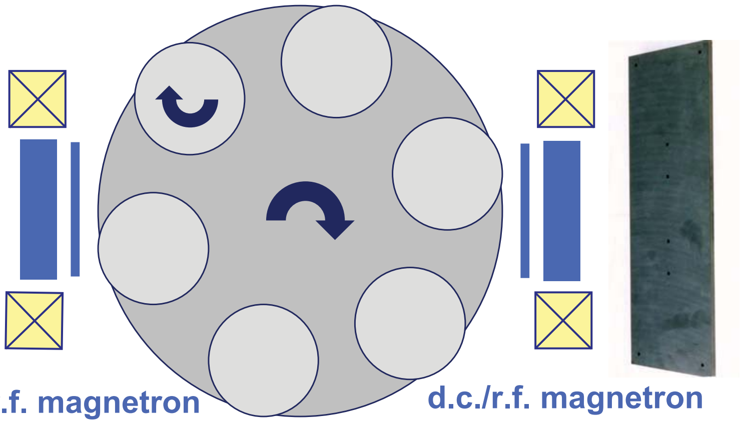
By courtesy of Dr. HaJo Scheibe
Fraunhofer IWS, Dresden

Hard a-C and ta-C films by novel hybrid PVD processes

Metaplas MZR 304/RF system at IAM

modular PVD/PA-CVD system

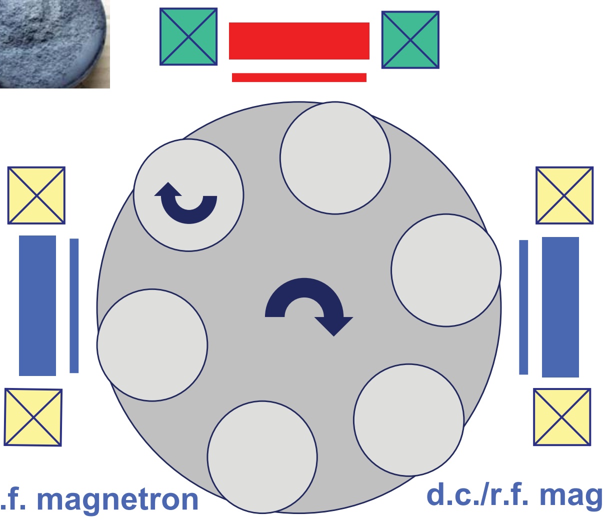
reactive d.c./r.f. magnetron sputtering



d.c./r.f. magnetron
graphite target

d.c./r.f. magnetron
graphite target

Hard a-C and ta-C films by novel hybrid PVD processes



advanced d.c. arc module

graphite cathode

d.c./r.f. magnetron

graphite target

d.c./r.f. magnetron

graphite target

<u>Metaplas MZR 304/RF system at IAM</u>

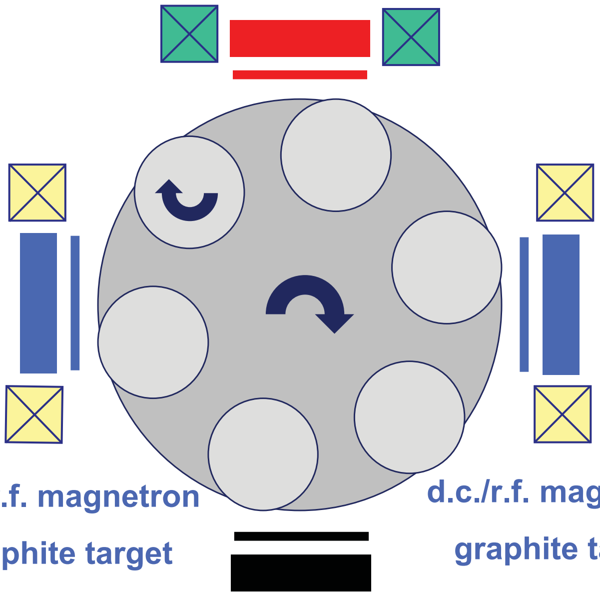
modular PVD/PA-CVD system

reactive d.c./r.f. magnetron sputtering

d.c. cathodic arc evaporation

magnetic field configuration tuning

Hard a-C and ta-C films by novel hybrid PVD processes



advanced d.c. arc module

graphite cathode

d.c./r.f. magnetron

graphite target

d.c./r.f. magnetron

graphite target

flexible flange position
(i.e. pulsed magnetron)

<u>Metaplas MZR 304/RF system at IAM</u>

modular PVD/PA-CVD system

reactive d.c./r.f. magnetron sputtering

d.c. cathodic arc evaporation

magnetic field configuration tuning

d.c./r.f. substrate bias

low temperature deposition up to 500°C

⇩

large variation in modification of

plasma density

plasma particle energies

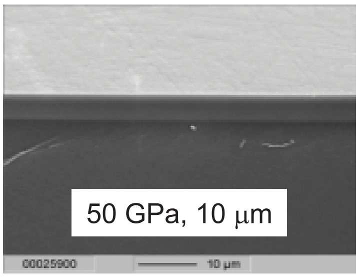
substrate current density

growth conditions for hard a-C films

Structure and properties of a-C and ta-C coatings

magnetron sputtering

temperature < 100°C, d.c./r.f. bias gradient



lab-scale process

stationary

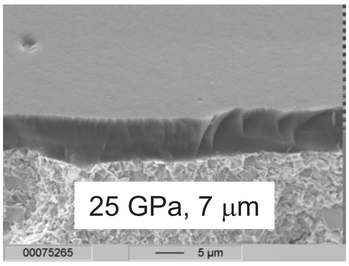
target: 11 W/cm^2

development

upscaled process

3-fold rotation

target: 4 W/cm^2

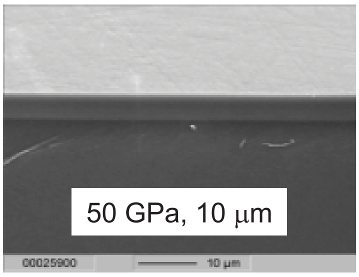


< 0,1	**A_{target}/A_{table}**	**~ 1**
< 10 cm	**$D_{target\text{-}table}$**	**>> 10 cm**

Structure and properties of a-C and ta-C coatings

magnetron sputtering

temperature < 100°C, d.c./r.f. bias gradient



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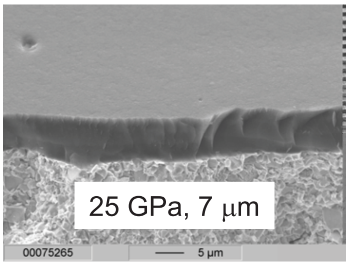
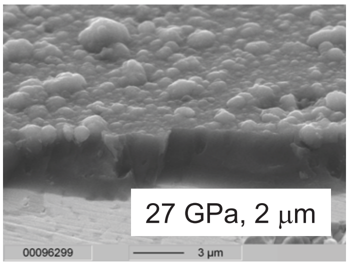


< 0,1	**A_{target}/A_{table}**	**~ 1**
< 10 cm	**$D_{target\text{-}table}$**	**>> 10 cm**

cathodic arc evaporation

temperature < 100°C, d.c. bias gradient



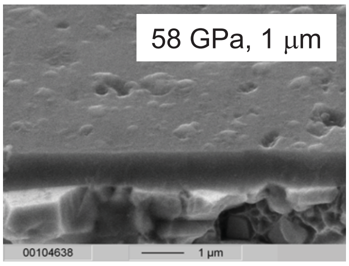
high current arc

start pressure: high

end pressure: low

lower current arc

low pressure



ta-C dependent on thermal process management ?

Industrial applications of DLC films - standardization

more than 100 data sets on industrially available DLC (and other carbon-based) coatings of various companies, job-coaters and end-users can be found at

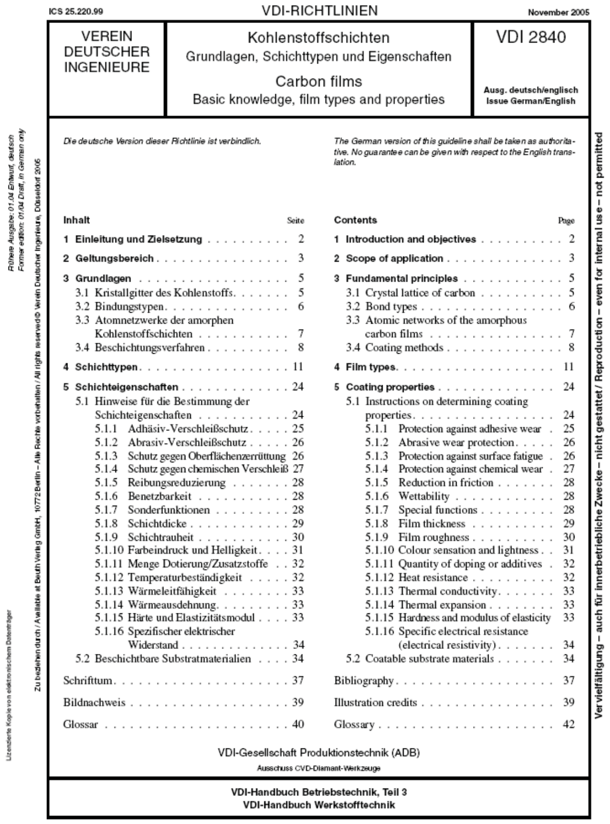
www.ist.fraunhofer.de

(focus mainly on Germany, Switzerland, Austria, The Netherlands)

→ strong need for harmonization

↓

Technical Guideline VDI 2840
of the Society of German Engineers



ICS 25.220.99
VDI-RICHTLINIEN
November 2005

VEREIN
DEUTSCHER
INGENIEURE

Kohlenstoffschichten
Grundlagen, Schichttypen und Eigenschaften

Carbon films
Basic knowledge, film types and properties

VDI 2840

Ausg. deutsch/englisch
Issue German/English

Die deutsche Version dieser Richtlinie ist verbindlich.

The German version of this guideline shall be taken as authoritative. No guarantee can be given with respect to the English translation.

Inhalt Seite

Contents Page

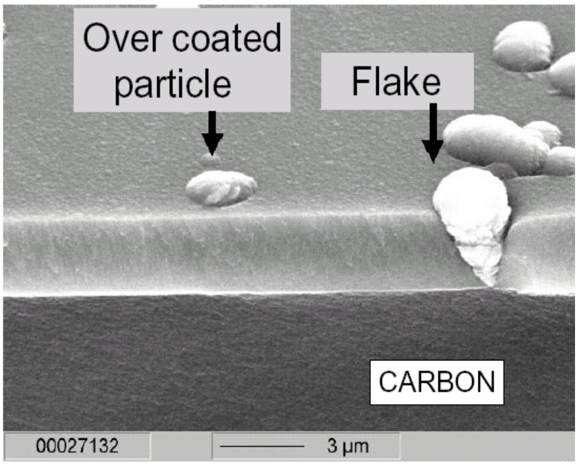
VDI-Gesellschaft Produktionstechnik (ADB)
Ausschuss CVD-Diamant-Werkzeuge

VDI-Handbuch Betriebstechnik, Teil 3
VDI-Handbuch Werkstofftechnik

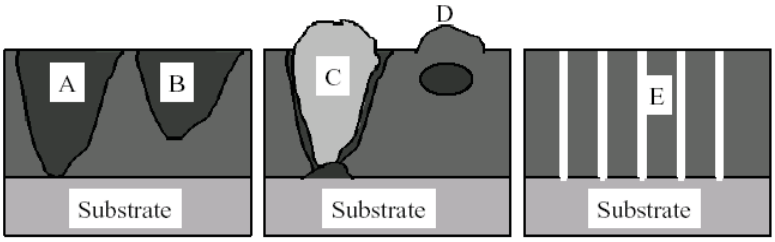
Frühere Ausgabe: 01.04 Entwurf, deutsch
Former edition: 01/04 Draft, in German only

DLC: Challenges – growth defects in PVD coatings

growth defects in magnetron sputtered carbon coatings:



J.Vetter, M.Stüber, S.Ulrich
Surf. Coat. Tech. 168 (2003) 169



Voids
A) till substrate
B) in the coating

Particles in the coating
C) flake formation
D) over coated particle

Morphology:
E) coarse columnar

DLC: Challenges – intrinsic stress and adhesion

objective: DLC deposition on metal substrates (i.e AISI 316 L)

ion bombardment during deposition

thermal expansion coefficients

DLC films with
high hardness
but
high residual stress

limited or poor adhesion

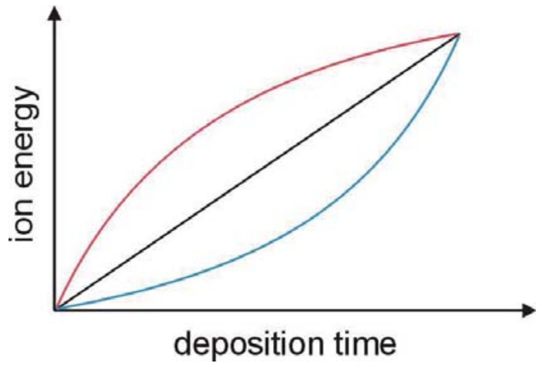
coating delamination

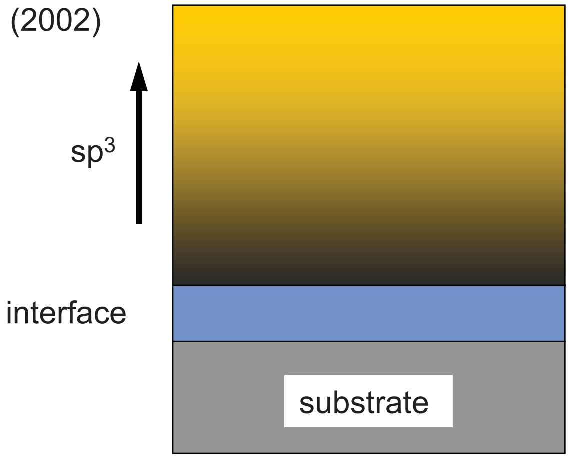
coating design for reducing the residual stress:

- additions of e.g. metal or N: a-C:X coatings
- multilayer concepts
- advanced gradient coating concepts

Advanced gradient coating concept for stress management

FZK-patents: US 6.110.129 (2000), EP 0912774 B1 (2002)





gradient superhard ta-C coatings on steel:

Vickers hardness 50 GPa, thickness 10 μm,

critical load of failure > 30 N, < 1 GPa stress

DLC: challenges – coating delamination and corrosion

DLC coatings for artificial hip joints

- **in vitro excellent performance of DLC**

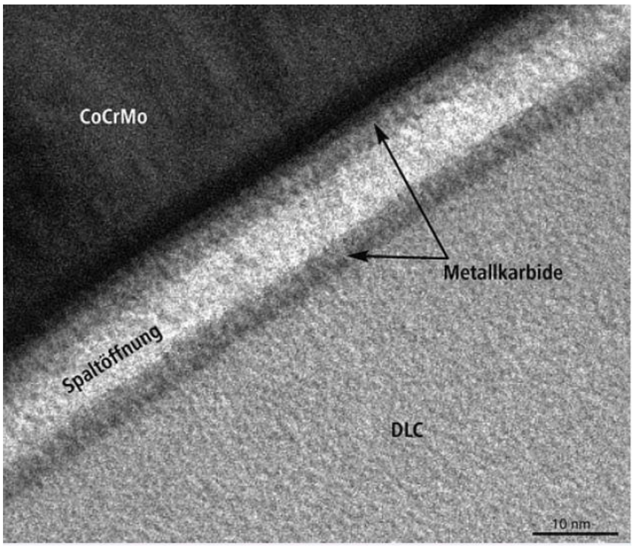
DLC as wear resistant, chemically inert and biocompatible functional coating

but !

- **in vivo: failure of implant**

due to failure of interface layer between implant and functional DLC coating by

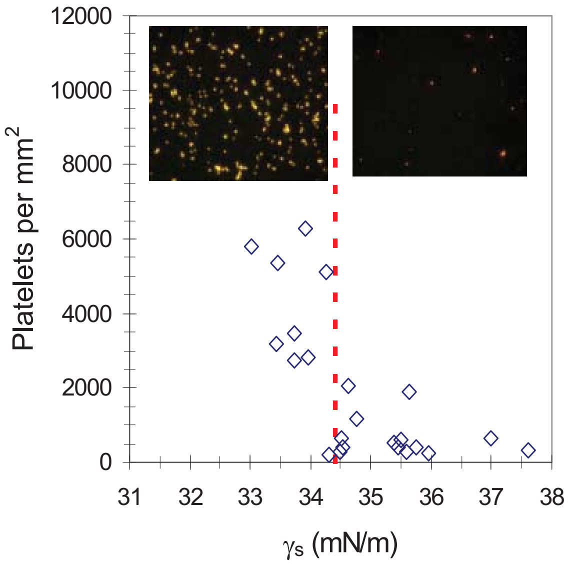
- crack formation at interface
- crack propagation through interface
- delamination of DLC coating
- corrosion of implant material

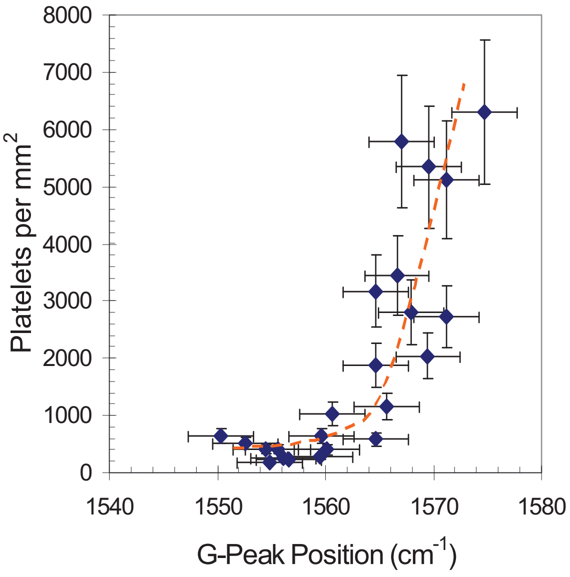


DGM News 2010
C.V.Falub et al., Acta Biomat. 5 (2009) 3086
U.Müller et al., Acta Materialia 59 (2011) 1150
R.Hauert et al., Diam. Rel. Mat. 25 (2012) 34
R.Hauert et al., Acta Biomat. 8 (2012) 3170

DLC: challenges – surfaces with predictable cell adhesion ?

adhesion of thrombocytes on magnetron-sputtered a-C:X coatings

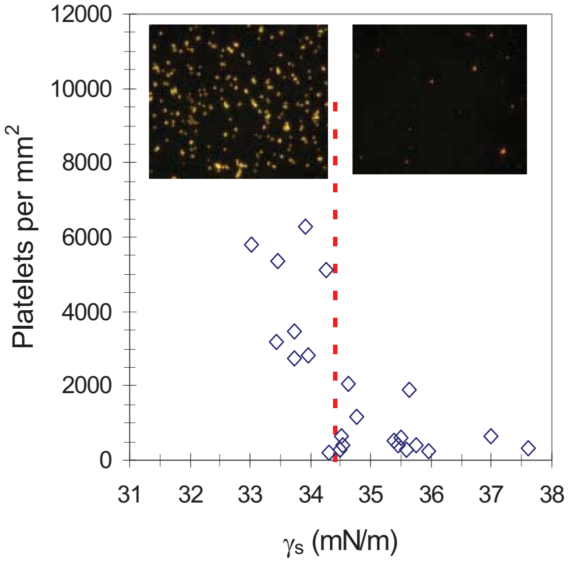


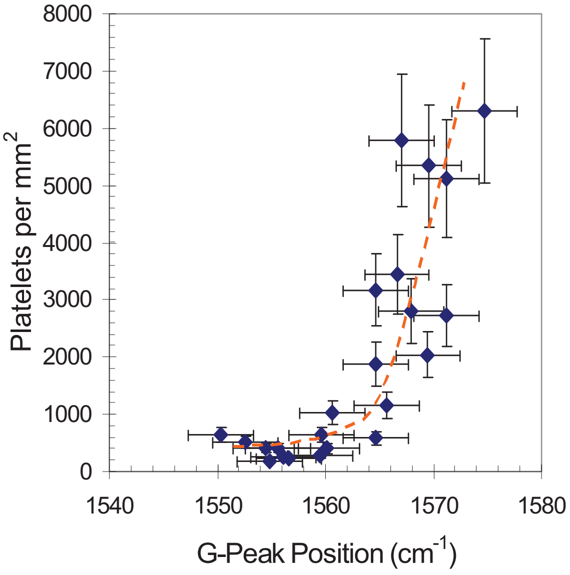


thrombocyte adhesion = f (surface energy, a-C:X constitution, morphology)

DLC: challenges – surfaces with predictable cell adhesion ?

adhesion of thrombocytes on magnetron-sputtered a-C:X coatings





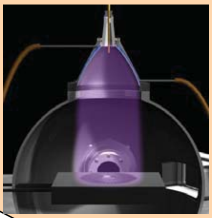
thrombocyte adhesion = f (surface energy, a-C:X constitution, morphology)

But: protein adsorption (Albumin, Fibrinogen, …) before cell adhesion ! ?

DLC for biomedical applications: future R&D issues

modelling & simulation of DLC growth

optimized DLC deposition processes



pulsed processes (HIPIMS)

hybrid processes

high rate deposition

DLC for biomedical applications: future R&D issues

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pulsed processes (HIPIMS)

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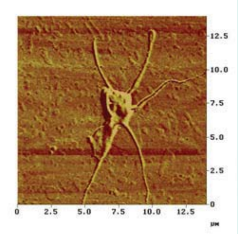


unspecific interactions

specific interactions

cell – surface interactions

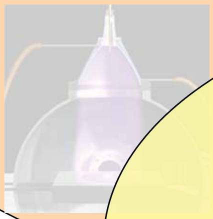
materials science – physics – chemistry - biology

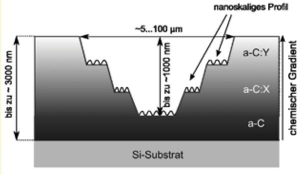
protein interaction at DLC surfaces

DLC for biomedical applications: future R&D issues

modelling & simulation of DLC growth

optimized DLC deposition processes





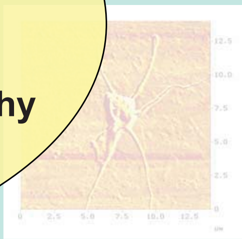
plasma chemical modification a-C:O:X

surface functionalization

DLC advanced surface topography

nanoscale surface re-arrangement

surface micropatterning



unspecific interactions

specific interactions

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protein interaction at DLC surfaces

Acknowledgement

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S.Ulrich, H.J.Seifert,

L.Niederberger, F.Danneil,

all colleagues of Department Composites and Thin Films (IAM-AWP),

A.Welle and team at IBG-1

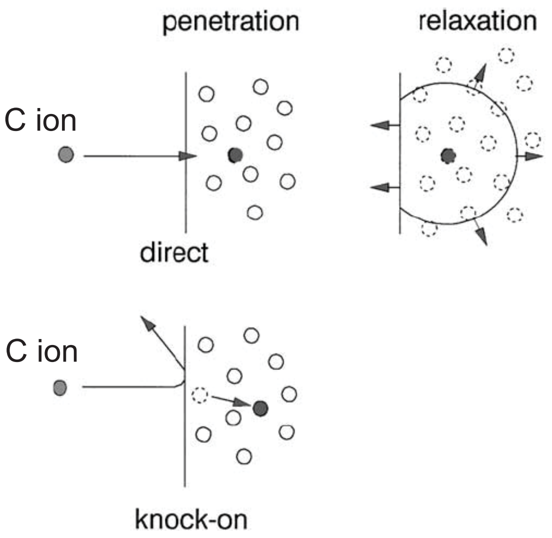
All colleagues quoted in the presentation

Thank you for your kind attention !

RESERVE

Growth mechanism in DLC films

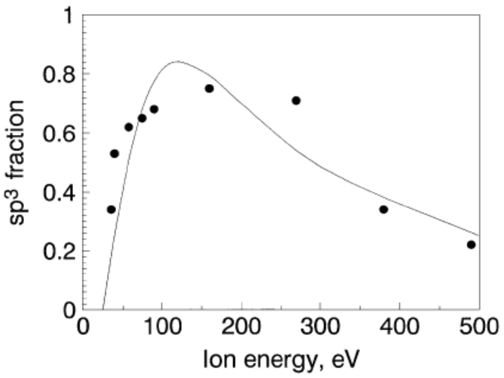
example: amorphous carbon, a-C



subplantation model

metastable increase in local density

local conversion of sp^2 to sp^3 sites



compressive stress & thermal spike models ?

J.Robertson, Pure & Appl. Chem. 66 (1994) 1789

Y.Lifshitz et al., Phys. Rev. B 41 (1990) 10468

J.Robertson, Mat. Sci. Eng. R 37 (2002) 129

S.Neuville, A.Matthews, Thin Solid Films 515 (2007) 6619

DLC films – R&D milestones and state-of-the-art

1953	H.Schmellenmeier DC glow discharge of C_2H_2
1971	S.Aisenberg, R.Chabot ion beam deposition from graphite
1976/77	L.Holland, S.M.Ohja RF glow discharge of C_4H_{10}
1979/80	C.Weissmantel et al. / K.Enke et al. friction and tribology of DLC
1981	F.K.King carbon films for magnetic recording media
1983	H.Dimigen et al. a-C:H:Me coating film family, Me = W, Ti, …
1986	J.Robertson, Adv. Phys. 35 (1986) 317
1990	D.R.McKenzie et al., H.J.Scheibe et al. arc techniques (filtered arc, laser arc)
1994	M.Grischke et al., and other groups a-C:H:X coating family, X = F, Si, O, B, N
1997/98 > 2000	A.Voevodin J.Zabinski et al. multilayers, gradient coatings, nano-composites, „chameleon coatings“

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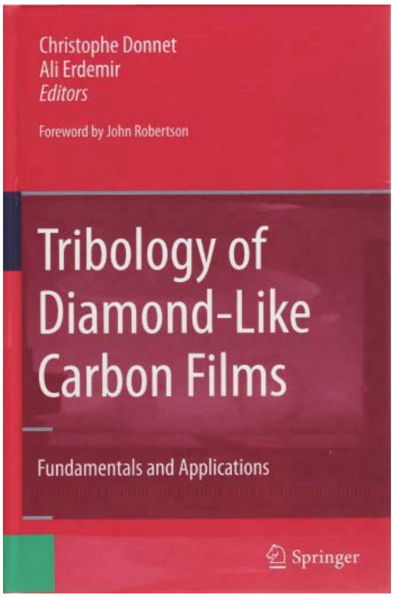

Christophe Donnet
Ali Erdemir
Editors

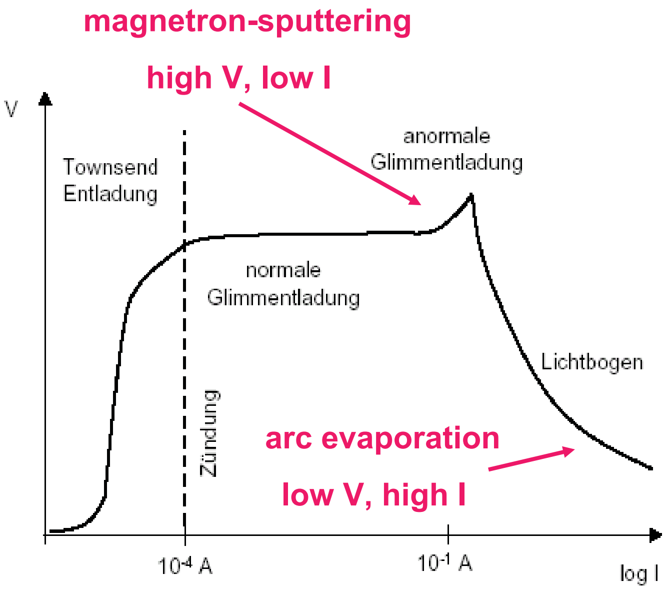
Foreword by John Robertson

Tribology of Diamond-Like Carbon Films

Fundamentals and Applications

Springer

Fundamental aspects of cathodic arc evaporation



voltage – current characteristics

of glow discharges

arc discharge: **collective electron emission**

glow discharge: individual electron emission

kinetic energy of particles 20 – 150 eV

(magnetron sputtering 5 – 10 eV)

highly or fully ionized arc plasma

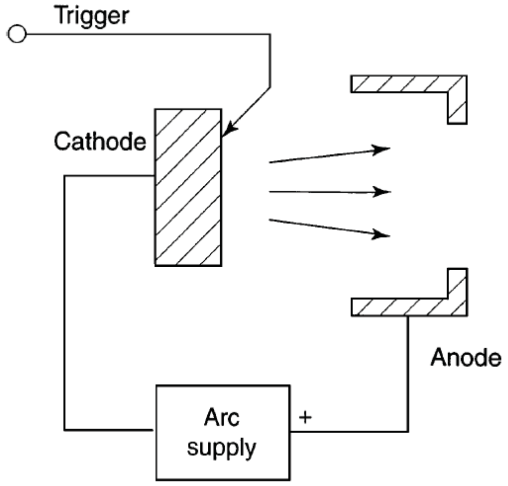
multiply charged ions

(carbon arc plasma: 60 - 100% C^+)

droplet & macroparticle emission

cathode spot dynamics = f (cohesive energy of cathode material & magnetic field configuration)

Some aspects of physics of cathodic vacuum arc



simplified schematic of basic cathodic arc configuration

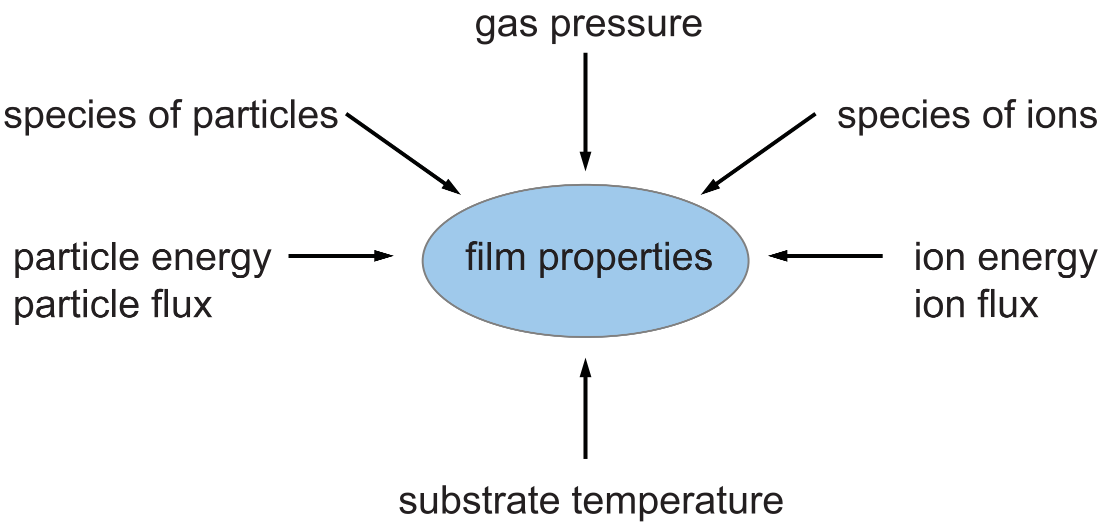
characteristics of cathodic vacuum arc

low-voltage, high-current plasma discharge
formation of discrete „cathode spots“
explosive emission process (including particles)

cathode spot size:	1 – 10 μm
current density at cathode spot:	$10^6 – 10^8$ A/cm^2
power density at cathode spot:	$10^7 – 10^9$ W/cm^2
electric field at cathode spot:	$10^4 – 10^5$ V/cm
temperature at cathode spot:	4000 – 40000 K
pressure at cathode spot:	0.1 – 10 MPa
lifetime of a spot at a fixed location:	10 ns – 1 μs
high ion density:	10^{13}/cm^2
multiple charge states:	Me^+, Me^{2+}, Me^{3+}
kinetic energy of ions:	10 – 200 eV

I.G.Brown, Annu. Rev. Mater. Sci. 28 (1998) 243

Control of deposition processes



gas pressure

species of particles

species of ions

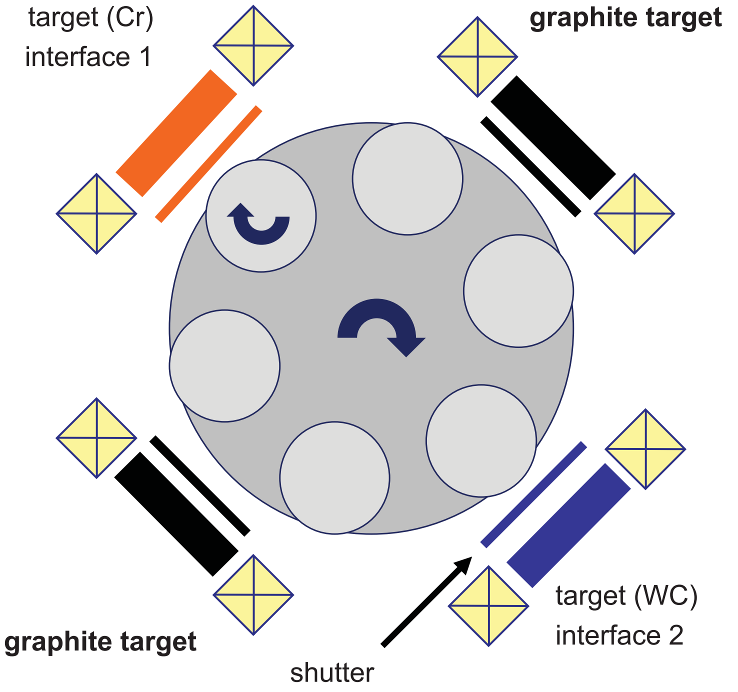
particle energy
particle flux

film properties

ion energy
ion flux

substrate temperature

DLC films by reactive d.c. magnetron sputtering (C-DLC)



K.Bewilogua et al, presentation at ICMCTF 2008, San Diego

process parameters & characteristics

reactive d.c. magnetron sputtering

graphite targets, UBM mode

target power density up to 8 W/cm^2

total gas pressure 0.2 – 0.4 Pa

variation of C_2H_2 gas flow

variation of d.c. substrate bias

variation of coil current

d.c. pulse (targets, substrate)

⇩

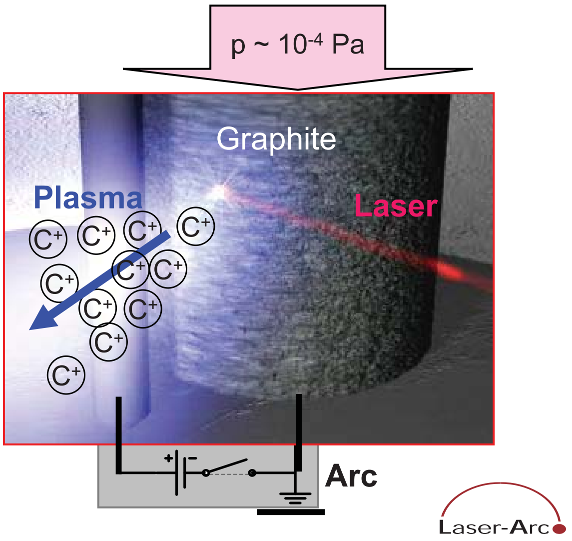
enhanced plasma density

increased substrate current density

coating type 2.4 (a-C:H), VDI 2840

DLC by laser controlled pulsed arc evaporation (Laser-Arc)

superhard, hydrogen free ta-C films



system industrially available ⟶ exhibition

P.Siemroth, H.J.Scheibe, IEEE Trans. Plas. Sci. 18 (1990) 911

process parameters & characteristics

pulsed laser arc plasma source

rotating graphite cathode

high vacuum process (10^{-4} Pa)

variation of pulsed arc current

variation of arc puls duration

variation of deposition temperature

variation of carbon incident angle on the substrate

⇩

highly ionized carbon plasma

high carbon ion energies (> 30 eV)

low substrate temperature (T < 100°C)

coating type 2.2 (ta-C), VDI 2840

VDI 2840 – classification of carbon coatings

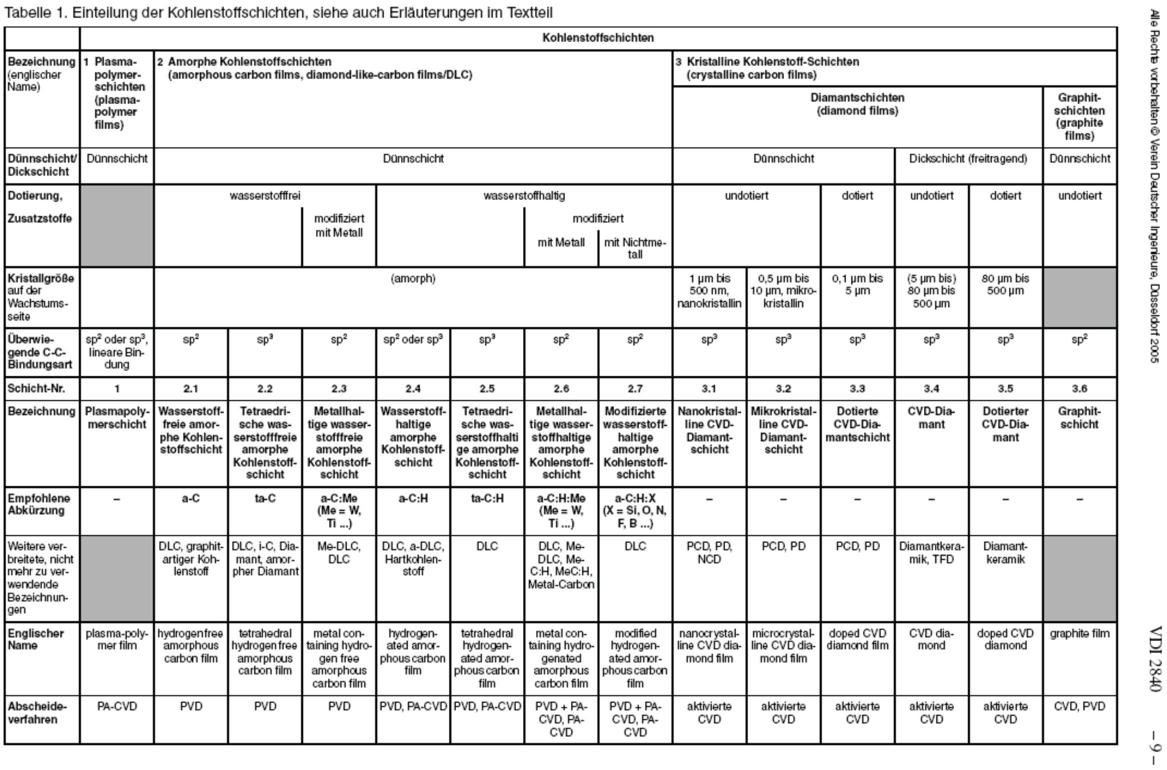


Tabelle 1. Einteilung der Kohlenstoffschichten, siehe auch Erläuterungen im Textteil

	Kohlenstoffschichten													
Bezeichnung (englischer Name)	**1 Plasmapolymerschichten (plasmapolymer films)**	**2 Amorphe Kohlenstoffschichten (amorphous carbon films, diamond-like-carbon films/DLC)**							**3 Kristalline Kohlenstoff-Schichten (crystalline carbon films)**					
									Diamantschichten (diamond films)					**Graphitschichten (graphite films)**
Dünnschicht/ Dickschicht	Dünnschicht	Dünnschicht							Dünnschicht			Dickschicht (freitragend)		Dünnschicht
Dotierung, Zusatzstoffe		wasserstofffrei			wasserstoffhaltig				undotiert		dotiert	undotiert	dotiert	undotiert
				modifiziert mit Metall			modifiziert							
							mit Metall	mit Nichtmetall						
Kristallgröße auf der Wachstumsseite		(amorph)							1 µm bis 500 nm, nanokristallin	0,5 µm bis 10 µm, mikrokristallin	0,1 µm bis 5 µm	(5 µm bis) 80 µm bis 500 µm	80 µm bis 500 µm	
Überwiegende C-C-Bindungsart	sp^2 oder sp^3, lineare Bindung	sp^2	sp^3	sp^2	sp^2 oder sp^3	sp^3	sp^2	sp^2	sp^3	sp^3	sp^3	sp^3	sp^3	sp^2
Schicht-Nr.	**1**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**
Bezeichnung	**Plasmapolymerschicht**	**Wasserstofffreie amorphe Kohlenstoffschicht**	**Tetraedrische wasserstofffreie amorphe Kohlenstoffschicht**	**Metallhaltige wasserstofffreie amorphe Kohlenstoffschicht**	**Wasserstoffhaltige amorphe Kohlenstoffschicht**	**Tetraedrische wasserstoffhaltige amorphe Kohlenstoffschicht**	**Metallhaltige wasserstoffhaltige amorphe Kohlenstoffschicht**	**Modifizierte wasserstoffhaltige amorphe Kohlenstoffschicht**	**Nanokristalline CVD-Diamantschicht**	**Mikrokristalline CVD-Diamantschicht**	**Dotierte CVD-Diamantschicht**	**CVD-Diamant**	**Dotierter CVD-Diamant**	**Graphitschicht**
Empfohlene Abkürzung	–	**a-C**	**ta-C**	**a-C:Me (Me = W, Ti ...)**	**a-C:H**	**ta-C:H**	**a-C:H:Me (Me = W, Ti ...)**	**a-C:H:X (X = Si, O, N, F, B ...)**	–	–	–	–	–	–
Weitere verbreitete, nicht mehr zu verwendende Bezeichnungen		DLC, graphitartiger Kohlenstoff	DLC, i-C, Diamant, amorpher Diamant	Me-DLC, DLC	DLC, a-DLC, Hartkohlenstoff	DLC	DLC, Me-DLC, Me-C:H, MeC:H, Metal-Carbon	DLC	PCD, PD, NCD	PCD, PD	PCD, PD	Diamantkeramik, TFD	Diamantkeramik	
Englischer Name	plasma-polymer film	hydrogenfree amorphous carbon film	tetrahedral hydrogen free amorphous carbon film	metal containing hydrogen free amorphous carbon film	hydrogenated amorphous carbon film	tetrahedral hydrogenated amorphous carbon film	metal containing hydrogenated amorphous carbon film	modified hydrogenated amorphous carbon film	nanocrystalline CVD diamond film	microcrystalline CVD diamond film	doped CVD diamond film	CVD diamond	doped CVD diamond	graphite film
Abscheideverfahren	PA-CVD	PVD	PVD	PVD	PVD, PA-CVD	PVD, PA-CVD	PVD + PA-CVD, PA-CVD	PVD + PA-CVD, PA-CVD	aktivierte CVD	aktivierte CVD	aktivierte CVD	aktivierte CVD	aktivierte CVD	CVD, PVD

VDI 2840 – 9 –

VDI 2840 – classification of carbon coatings

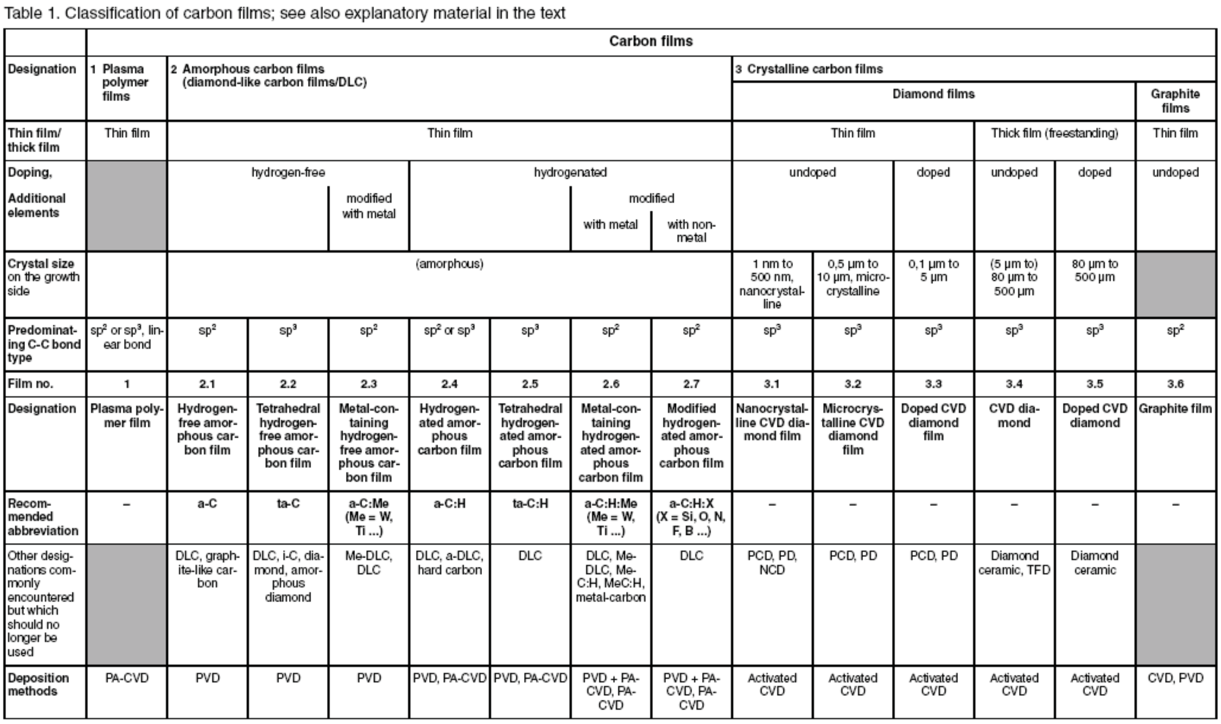


Table 1. Classification of carbon films; see also explanatory material in the text

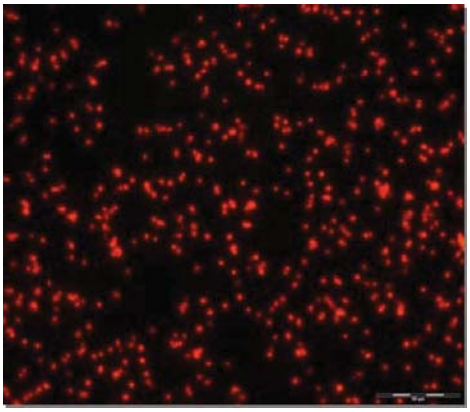
	Carbon films													
Designation	**1 Plasma polymer films**	**2 Amorphous carbon films (diamond-like carbon films/DLC)**							**3 Crystalline carbon films**					
									Diamond films					**Graphite films**
Thin film/ thick film	Thin film	Thin film							Thin film			Thick film (freestanding)		Thin film
Doping, Additional elements		hydrogen-free			hydrogenated				undoped		doped	undoped	doped	undoped
				modified with metal			modified							
							with metal	with nonmetal						
Crystal size on the growth side		(amorphous)							1 nm to 500 nm, nanocrystalline	0,5 µm to 10 µm, microcrystalline	0,1 µm to 5 µm	(5 µm to) 80 µm to 500 µm	80 µm to 500 µm	
Predominating C-C bond type	sp^2 or sp^3, linear bond	sp^2	sp^3	sp^2	sp^2 or sp^3	sp^3	sp^2	sp^2	sp^3	sp^3	sp^3	sp^3	sp^3	sp^2
Film no.	**1**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**
Designation	**Plasma polymer film**	**Hydrogen-free amorphous carbon film**	**Tetrahedral hydrogen-free amorphous carbon film**	**Metal-containing hydrogen-free amorphous carbon film**	**Hydrogenated amorphous carbon film**	**Tetrahedral hydrogenated amorphous carbon film**	**Metal-containing hydrogenated amorphous carbon film**	**Modified hydrogenated amorphous carbon film**	**Nanocrystalline CVD diamond film**	**Microcrystalline CVD diamond film**	**Doped CVD diamond film**	**CVD diamond**	**Doped CVD diamond**	**Graphite film**
Recommended abbreviation	–	**a-C**	**ta-C**	**a-C:Me (Me = W, Ti ...)**	**a-C:H**	**ta-C:H**	**a-C:H:Me (Me = W, Ti ...)**	**a-C:H:X (X = Si, O, N, F, B ...)**	–	–	–	–	–	–
Other designations commonly encountered but which should no longer be used		DLC, graphite-like carbon	DLC, i-C, diamond, amorphous diamond	Me-DLC, DLC	DLC, a-DLC, hard carbon	DLC	DLC, Me-DLC, Me-C:H, MeC:H, metal-carbon	DLC	PCD, PD, NCD	PCD, PD	PCD, PD	Diamond ceramic, TFD	Diamond ceramic	
Deposition methods	PA-CVD	PVD	PVD	PVD	PVD, PA-CVD	PVD, PA-CVD	PVD + PA-CVD, PA-CVD	PVD + PA-CVD, PA-CVD	Activated CVD	Activated CVD	Activated CVD	Activated CVD	Activated CVD	CVD, PVD

FZK project MEDICOAT – cell adhesion testing

Bestimmung der Thrombozytenadäsion

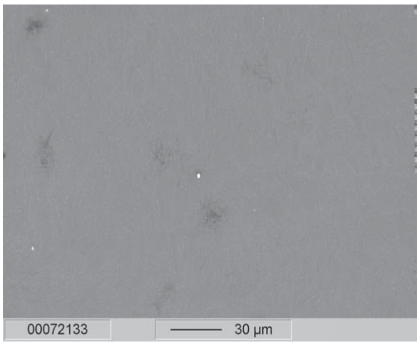
Messung nach Methode von Breddin und Brück

- Bereitstellung von frischem Citratblut (Eigenblut)
- zentrifugieren, bis sich PRP (platelet rich plasma) absetzt
- auf in Citratpuffer vorinkubierte Proben aufbringen
- 1h im Brutschrank bei 37° C auslagern
- Proben waschen
- Thrombozyten mit Fluoreszenzfarbstoff (Rhodamin 6G) einfärben
- Auszählung der Thrombozyten im Mikroskop

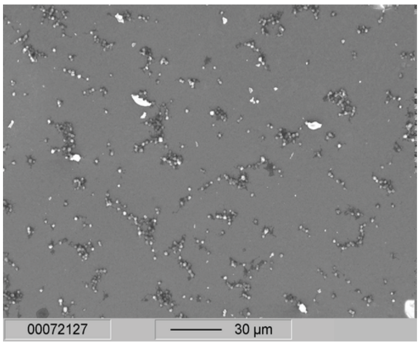


MEDICOAT – thrombocytes adhesion on a-C:X coatings

a-C coating with low thrombogenicity



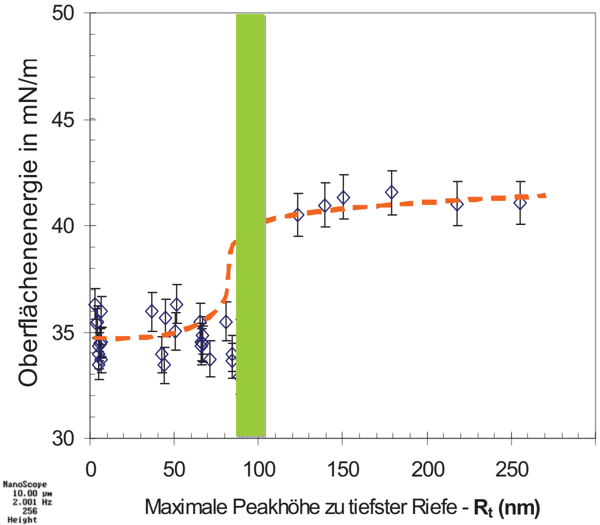
a-C coating with high thrombogenicity

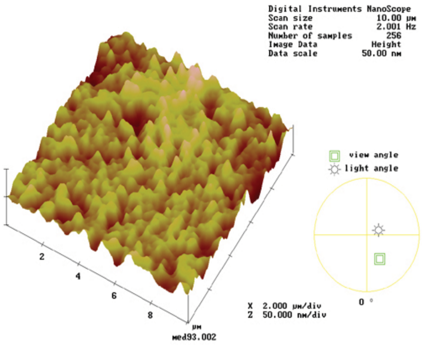


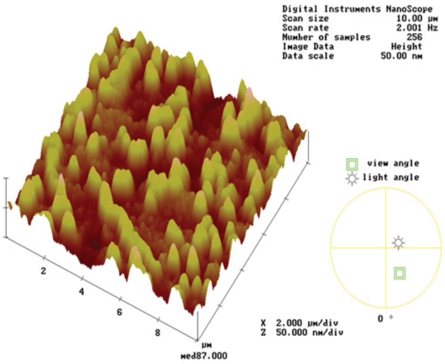
1550 – 1560 cm^{-1}	Raman spectroscopy: G-band position	1565 – 1580 cm^{-1}
34 – 40 mN/m	surface energy	30 – 34 mN/m
5 – 9 mN/m	polar fraction of SE	9 – 15 mN/m
65° - 77°	wetting angle of H_2O_{dest}	78° - 90°

thrombocyte adhesion = f (surface energy, a-C constitution, morphology)

MEDICOAT – thrombocytes adhesion on a-C:X coatings







significance of R_t

for surface energy