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CLASSIFICATION OF HYDROCARBON FILMS OBTAINED IN TOKAMAK T-10 UNDER CONTROLLED CONDITIONS

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Motivation

Possible co-deposition of carbon and hydrogen in form of a-C:H(D,T) films on walls and optical elements of plasma diagnostics inside vacuum chamber of today's tokamaks and ITER

Goal

Characterization and classification of a-C:H films obtained at pulsed, steady-state and mixed PSI regimes under ITER relevant conditions

Experimental methods

- XPS (X-ray Photoelectron Spectroscopy):
  Composition and chemical states (3 nm depth)
- Ellipsometry:
  Optical parameters (n-ik, d) of a-C:H films at λ = 632.8 nm
- Spectrophotometry:
  Reflective spectra in the range of 190-1100 nm
- SEM & OM:
  Surface morphology

Summary

Amorphous hydrocarbon (a-C:H) films deposited at pulsed (QSPA and tokamak T-10), steady-state (magnetron and T-10) and mixed (T-10) PSI regimes were studied and classified. Wide range (from soft to hard) of a-C:H films was found in T-10. For example, "pulsed" QSPA films can be placed between soft "steady-state" and hard "pulsed" films from T-10. Optical parameters (n-ik) of "steady-state" films are compatible with "mixed" free standing films and "steady-state" films from magnetron as well. At the same time, remarkable concentration of metallic impurities was observed on "pulsed" QSPA films only. Moreover, dependence of optical parameters of QSPA and T-10 films on temperature should be clarified (the higher temperature the softer a-C:H film?)

References

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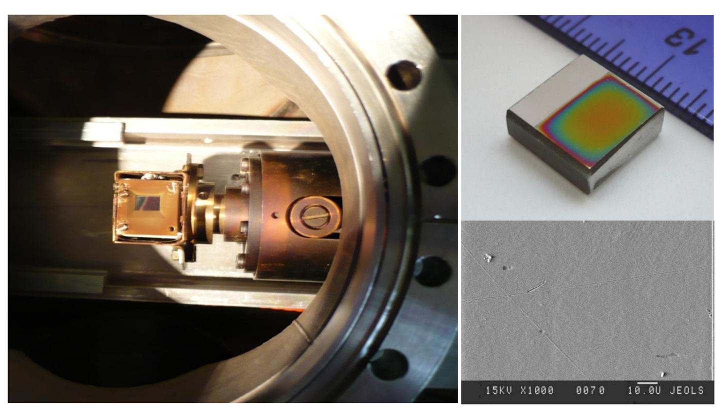
Magnetron, "Kurchatov Institute"

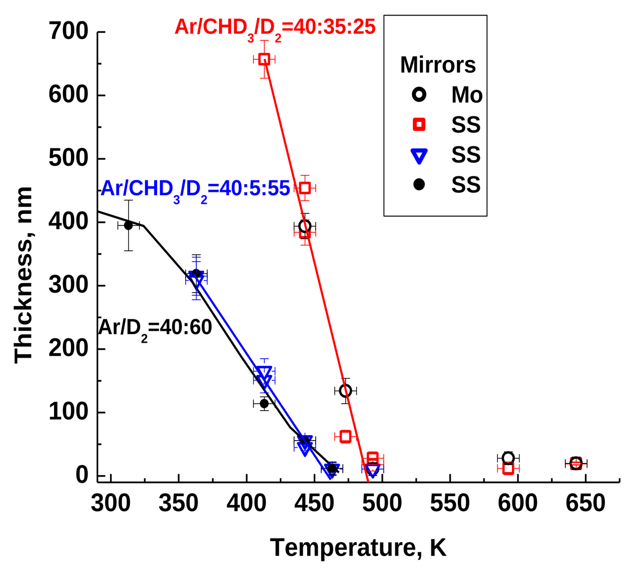
•Steady-state regime

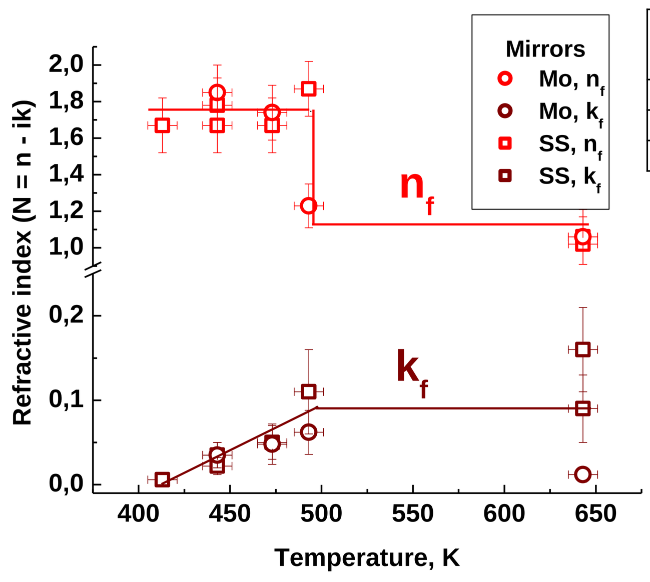


Discharge parameters

- Working gas – Ar/CHD_3/D_2
- Exposure time = 120 min
- P = 8 Pa
- $T_e \approx 10$ eV
- $n_e \approx 2\times10^{16}$ m^{-3}
- $T_i \approx 280$ eV
- Carbon flux ≈ 4×10^{18} $m^{-2}s^{-1}$
- $\langle E_C \rangle \approx 8$ eV*
- 313 K≤ T_{mirror} ≤643 K

Thickness and refractive index vs deposition temperature





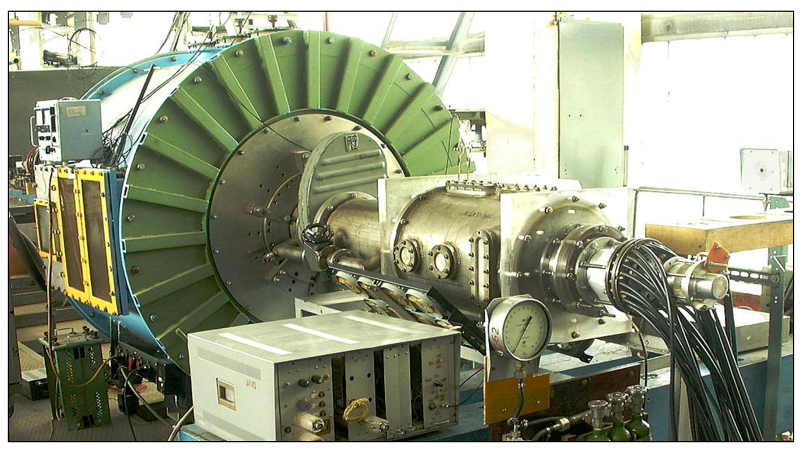
Results**

Gas mixture composition	a-C:H film properties, λ = 632.8 nm, T≈350 K				
	n	k	H/(H+C), at. %	H/C, at. %	ρ, g/cm³
Ar/D_2=40:60	1.69	0.01	44	80	1.2
Ar/CHD_3/D_2=40:5:55	1.71	0.02			
Ar/CHD_3/D_2=40:35:25	1.67	0.006			

1. The higher temperature the larger extinction coefficient
2. Deposition rate strongly depends on gas content
3. Deposition rate not depends on material of substrate (Si, SS or Mo)
4. No metallic dust and impurities

QSPA-T, "SRC RF TRINITI"

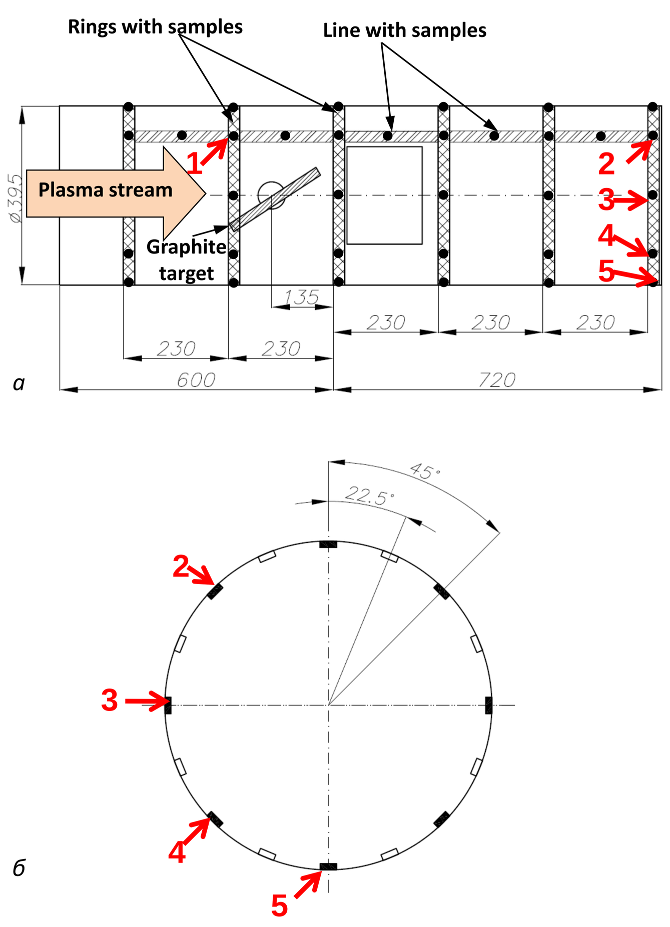
•Pulsed regime



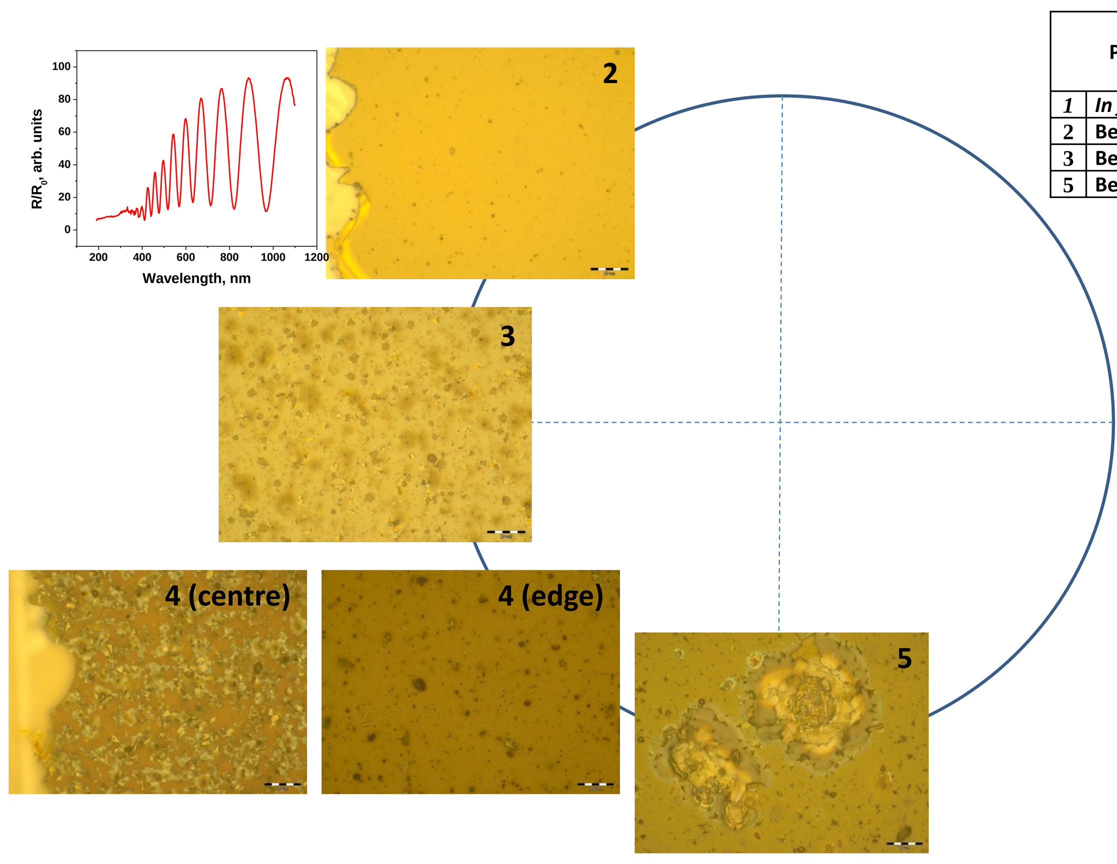
Plasma parameters

- •Working gases: H_2, D_2 and Ar
- • Pulse duration: Δt = 0.2 ÷ 0.6 ms
- • Stream velocity: V = (1÷3)×10^5 m/s
- • Stream diameter: Ø = 5 cm
- • Plasma density: $n_e = 10^{22} \div 10^{23}$ m^{-3}
- • Electron temperature: T_e = < 10 eV
- • Ion (H^+) energy: E_i = 0.1 ÷ 0.5 keV
- • Heat load: Q = 0.2 ÷ 5 MJ/m²

Scheme of experiment



Surface morphology



Results

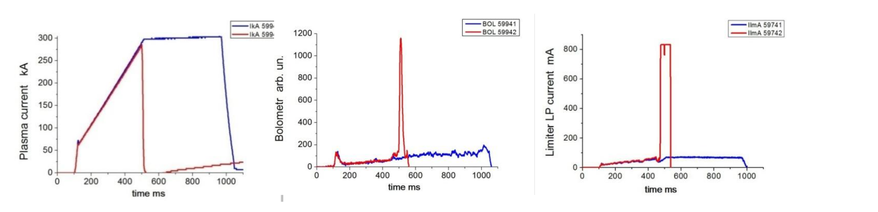
	Position of sample	Deposition rate, nm/pulse	Optical parameters at λ = 632.8 nm			Hydrogen content & Density***	
			n	k	h, nm	H/(H+C), at. %	ρ, g/cm³
1	*In front of target, up*	*9.3*	*1.57*	*0.007*	*1860*	*45*	*1.2*
2	Behind the target, up	6.6	1.52	0.004	1320	47	1.0
3	Behind the target, centre	12.4	1.63	0.017	2470	43	1.3
5	Behind the target, down	8.3	1.81	0.050	1650	41	1.4

1. The higher temperature the softer a-C:H film (?)
2. "Pulsed" QSPA films are placed between soft "steady-state" and hard "pulsed" films from T-10
3. Cu, Fe, Zn, W and traces of Cr are presented in all a-C:H films (from 0.1 to 2 at. %)

Токамак T-10, "Kurchatov Institute"

•Pulsed , steady-state and mixed regimes

Working discharge: stable pulse (blue) or disruption (red)



T-10 tokamak:

- R = 1.5 m
- a = 0.33 m (ring graphite limiter)
- b = 0.30 m (rail graphite limiter)

Working discharge:

- Working gas – D_2
- Pulse duration – 1 s
- $n_e \approx 1\times10^{20}$ m^{-3}
- B_t = 2.5 T
- I_p = 300 kA

Training AC discharge:

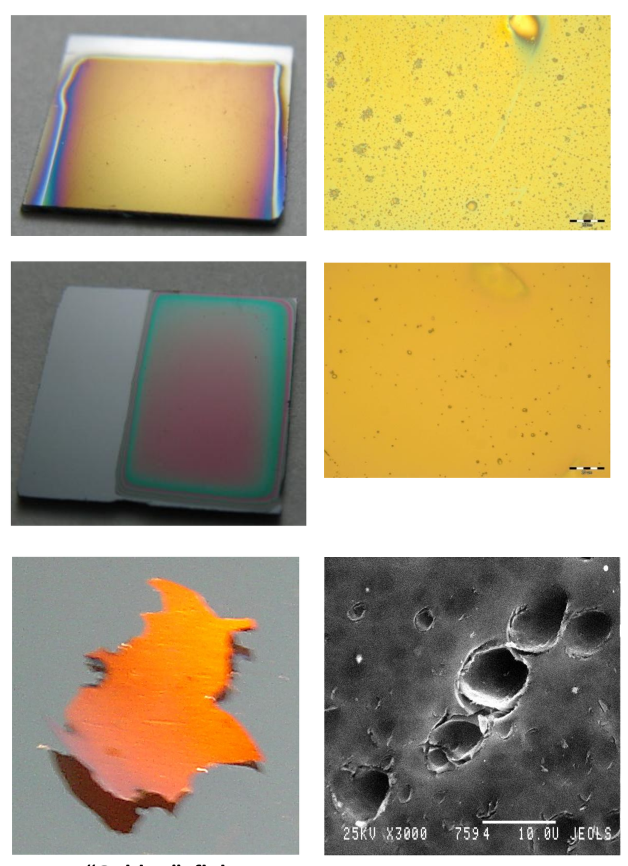
- Working gas – D_2
- Exposure time – 180 min/day
- P = 5×10^{-3} Pa
- ν = 50 Hz
- B_t = 0.05 T
- $I_{p\,(max)}$ = 5 kA

Surface morphology

Pulsed regime: working discharges

Steady-state regime: inductive AC discharges

Mixed regime: working & training discharges



"Golden" flake d=20 μm, S≈0.5 cm²

Plasma facing-side of the flake

Results

Regime	Stable pulses/ Disruptions	Exposure time	T, K	Deposition rate	a-C:H film properties, λ = 632.8 nm				
					h	n	k	H/(H+C) at. %	ρ g/cm³
Pulsed	280/20	≈ 300 s	≤350	0.37 nm/pulse	110 nm	1.98	0.14	37	1.7
	217/83	≈ 300 s	≤350	0.50 nm/pulse	150 nm	2.31	0.81	28	2.0
Steady-state	-/-	1920 min	500	0.44 nm/min	840 nm	1.54	0.00	47	1.0
Mixed	+/+	+	≤500		20 μm	1.54?		≈47	

1. Wide range of a-C:H films: from soft "steady-state" (n = 1.54) to hard "pulsed" (n = 2.31)
2. No metallic impurities inside free standing films (flakes) and a-C:H films on Si and SS substrates

Size & properties of clusters