Silicon Carbide thin films for EUV deposited with emerging PVD techniques

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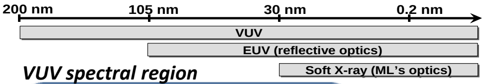
ABSTRACT

Silicon carbide (SiC) is an attractive material for EUV and soft X-ray optics. CVD-deposited SiC is the best reflective material in the whole EUV interval. Despite of this, SiC thin films deposited with PVD techniques, such as magnetron sputtering with amorphous structure, do not have the same performances undergoing to a degradation with time, probably because of the stoichiometry. Depositing stable SiC with PVD techniques is crucial in building ML's, like Si/SiC and SiC/Mg for soft X-ray applications (such space telescope). We deposited some preliminary samples using the Pulsed Laser Deposition (PLD) and the Pulsed Electron Deposition (PED) techniques achieving a good reflectance in the whole EUV range (27% at 10° of incidence at 121.6 nm) on a silicon substrate.The higher energy involved in these deposition processes could lead to a film with a stoichiometry much closer to the target one.

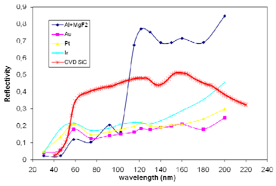
A good target is still a challenge since commercial SiC sintered target are usually not stoichiometric.

The reflectivity of the deposited films have been measured at LUXOR laboratory (University of Padova, Italy) and at the BEAR beamline of the ELETTRA synchrotron in Trieste (Italy).



VUV spectral region

- Below 200 nm absorption of the air is not negligible and instruments need to work in High Vacuum (HV)
- At wavelengths shorter than 105 nm no transmission optics can be used
- complex refractive index: n=1-δ+ik (n=1- δ)
- Fresnel normal incidence reflectance: R=|(1-n)/(1+n)|2 =(δ2 + k 2)/4
- Below 30 nm (Soft X-ray) δ, k « 1 → R < 10-4
  → optics must be used at grazing incidence in order to take advantage of total reflection
  → Multilayers optics (ML's)

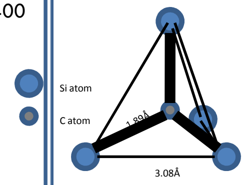


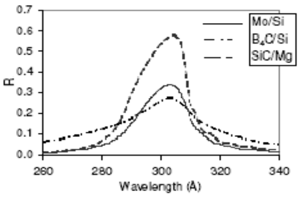
SiC optical coatings for EUV Soft X-ray

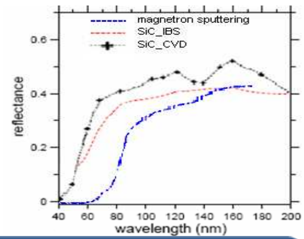
- Low scatter surface (after polishing)
- Good thermal and mechanical properties (less sensitive to temperature, presence of corrosive gases or high energy particles)
- CVD Silicon Carbide has one of the highest reflectance in the EUV region. It has already been chosen for space missions (SOHO,FUSE).
- Application in multilayer for the 30.4 nm (He II line) coupled with Mg (SiC/Mg best 30.4 nm reflectivity) or with Si (Si/SiC tunable ML)

Deposition techniques of SiC

- CVD → monocrystalline β-SiC T=1400
- Magnetron sputtering
  Ion beam sputtering
  + Suitable for multilayer
  + lower temperature
  + lower cost
  – worse performances than CVD
  – only amorphous SiC
  – Reflectivity degradation







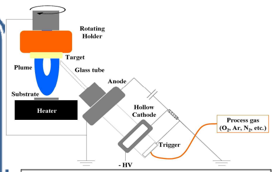
Pulsed deposition techniques

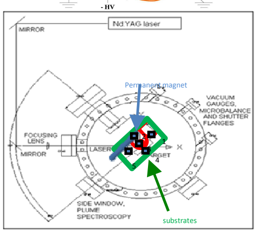
- Very high heating rate of the target surface (108 K/s)
- Deposition of crystalline film demands a much lower substrate temperature
- Stoichiometry of the target can be retained
- Particulate generation
  →exfoliational and hydrodynamical-sputtering.
  →Related to the laser parameters: wavelength, fluence and pulse duration

Pulsed Electron Deposition @IMEM-CNR

The electron beam has typical values:

- current of less than 1 kA
- energy around 15 keV
- maximum discharge voltage 25kV
- power density exceeding 108 W/cm2
- penetration depth of 1-2 μm
- fast (100 ns) ablation, leading to a non-equilibrium heating that preserves the stoichiometric material transfer from the target to the substrate





Pulsed Laser Deposition @LUXOR

- Laser: Nd:YAG (λ = 1064 nm) with pulses of 6ns and withan incidence angle of 45° on the target
- Target: SiC hot pressed 99.5%
- Magnetic field intensity on target: 100 – 200 Gauss
- Target-magnet distance: 15 mm
- Laser fluence: 2.1 J/cm2
- Target-substrate distance: 65 mm
- Time of deposition: 30'
- Five samples deposited with different position relative to the target

Stoichiometry and surface analysis on the samples and the SiC target

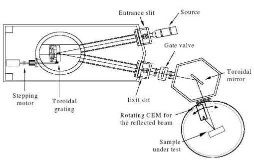
- X-ray Phoptoemissione Spectroscopy (XPS) measurements were taken with a modified VG ESCALAB MkII
- Mg K-alfa source
- The hemispheric electron analyzer works with a pass energy of 20 eV and the final resolution is 0.9 eV
- Samples and target were annealed at 700° C
- Sample PED_1 and PLD_2 were also sputtered with 2,5 KeV Ar+ ion
- The target bulk stoichiometry has been also retrieved by means of X–ray fluorescence (XRF) spectroscopy
- AFM measurements have been carried with a Park XE-70 @LUXOR

Sample	C At%	Si At%	O At%	N At%
SiC_PED1	41%	25%	32%	0.9%
SiC_PED1 S+A	30%	39%	30%	1%
SiC_PLD2	40%	31%	28%	0.4%
SiC_PLD2 S+A	27%	56%	17%	-
SiC_PED4	32%	28%	39%	traces
SiC_PED4 A	22%	33%	45%	traces

SiC Target (XPS)
C 62%
Si 16%
O 18%
SiC Target (XPS annealed)
C 50 %
Si 27%
O 18%
SiC Target XRF
61.35%
37.37 %

R measurements @LUXOR

- Source: hollow cathode or spectral lamps (40-500 nm)
- Monochromator: Johnson Onaka, normal incidence
- Detector: Channel Electron Multiplier or photomultiplier
- Sample and detector on manual stages
- Polarization factor known (from 121.6 to 40 nm)

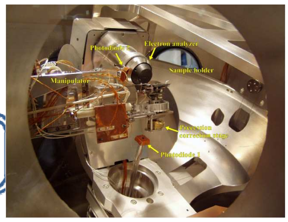


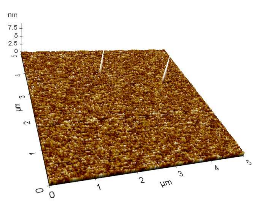
Reflectance measurements @BEAR ELETTRA Synchrotron

- Measurements down to 5 nm

AFM measurements

PSD	F1(1/m)	F2(1/μm)	PSD1(fm⁴)	PSD2(nm⁴)	P12(nm²)	Rq12(pm)	P(nm²)	Rq(pm)
2D	0.000	25.600	0E0	1.774E-1	0.025	158.191	0.02	158.191





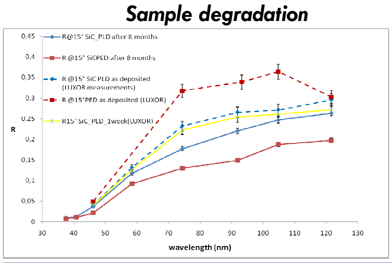
- Three reflectance value series by measuring R in two planes relatively rotated 90°

$$R_A = \frac{I_p R_p + I_s R_s}{I_p + I_s} = \frac{R_p + \alpha R_s}{1+\alpha}$$

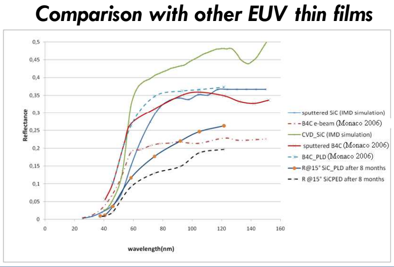
$$R_B = \frac{I_s R_p + I_p R_s}{I_p + I_s} = \frac{R_s + \alpha R_p}{1+\alpha}$$

$$\frac{R_1 + R_2}{2} = \frac{R_p + R_s}{2} = R_{average}$$

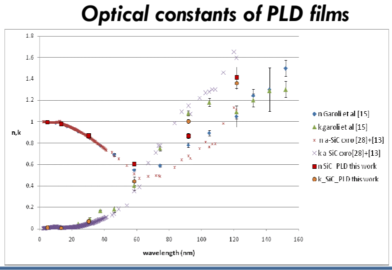
Sample degradation



Comparison with other EUV thin films



Optical constants of PLD films



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Essential references: G.Monaco *et al.*"Silicon carbide thin films for EUV and soft X-ray applications" *European Physical Journal-Special Topics* Volume 169 (1) , 2009; G.Monaco *et al.* "Optical constants of silicon carbide deposited with emerging PVD techniques" *SPIE proceeding vol.* 7360, 2009; Garoli et al. "Reflectance measurements and optical constants in the extreme ultraviolet-vacuum ultraviolet regions for SiC with a different C/Si ratio". *Appl. Opt.* 2006, Vol. 45(22), p 5642; S. Zuccon, *et al* "Multilayer Coatings for multiband spectral observations. *Proc. 6th Internat. Conf. on Space Optics.* 2006; J. B. Kortright and D. L. Windt *Appl. Opt. 27, 2841–2846 (1988);* Larruquert et al.,*Appl. Opt. 39 (2000);* DGaO Proceedings2009 -- /http://www.dgao-proceedings.de/ -- ISSN: 1614-8436