*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-2.128 (2002)*

Development and Characterization of Ultra-thin Diamond-like Carbon Foils for Particle Diagnostics in Laboratory and Space Plasmas

V.Kh. Liechtenstein [a, 1)], V.I. Afanasyev [b], P.Yu.Babenko [b]
E.A. Gridneva[c], T.M. Ivkova[a], V.A. Kurnaev [c], E.D. Olshansky [a],
M.P. Petrov [b], O.L. Vaisberg [d], K.Yu. Vukolov [a]

a – RRC "Kurchatov Institute", 123182 Moscow, Russia
b - A.F. Ioffe Physical – Technical Institute, 194021 St. Petersburg, Russia
c - Moscow Engineering Physical Institute, 116409 Moscow, Russia
d - Space Research Institute, 117810 Moscow GSP-7, Russia

INTRODUCTION

Thin carbon target foils are commonly used as strippers or secondary – electron emitters in a variety of particle analyzers for diagnostics of laboratory and space plasmas, with ultimate energy resolution and detection efficiency of the apparatus determined, to a large extend, by properties of the target foil [1]. Amorphous diamond-like carbon (DLC) foils developed at Kurchatov Institute [2], have shown recently to be well suited as ultra-thin ($\leq$ 1μg/cm^2) target foils owing to their very high mechanical and irradiation stability as well as enhanced secondary-electron yield [3]. This resulted particularly, in successful application of DLC target foils in the neutral particle analyzers for diagnostics of high temperature plasma in tokamaks JET, TFTR, JT-60U [4, 5] as well for particle diagnostics in interplanetary space within the frames of projects "Relikt" and "Interball". It is proposed also, to explore such foils in neutral particle analyzers dedicated for diagnostic of fusion plasma in ITER. In this paper, development of DLC foil targets is briefly described. Also, some results of the measurements of energy loss straggling and angle scattering of low energy light ions penetrating through the foils are presented as well as results on the foils stability under neutron radiation similar to that expected at ITER.

[1)] Corresponding author. E-mail address:liechten@nfi.kiae.ru

PREPARATION OF DLC TARGET FOILS

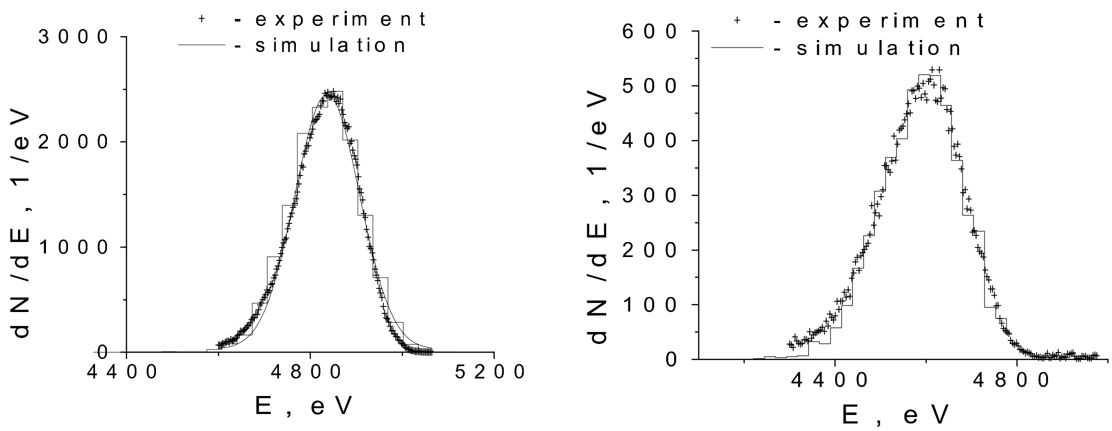
The DLC foils were produced by the special-purpose d.c. glow discharge sputtering of graphite in a low density krypton plasma. Carbon atoms are condensed onto glass slides which are coated with a release agent and cooled to liquid nitrogen temperature. A detailed description of the deposition technique is given in [2,3]. Characteristic properties of DLC deposits - extreme hardness (~ 20GP) and low electrical conductivity (~5x 10^{-4} Ω/cm^2) - are within the scatter of published data for a large variety of nonhydrogenated DLC films with sp^3 diamond content of about 30%. After deposition, the DLC foils were floated off in distilled water and picked up on target holders.

DLC target foils with a nominal thickness (measured surface density of the carbon) as small as 0.6$\mu g/cm^2$ (~3 nm) when supported with a 90% transmittance mesh a can be produced by this technique. The nominal thickness of the foils on glasses were measured optically with the aid of small monochromator, precalibrated by weighting of thicker (1-20 $\mu g/cm^2$) foil samples. A flat and smooth supporting mesh is of great importance for optimal performance and rigidity of ultra-thin carbon foils. To meet these requirements, the specific heat treatment of the pre-mounted foil holders was used. This allow us to fabricate exceptionally flat and rugged meshed holders, enabling DLC target foils with an active diameter as large as 70mm to be produced.

MEASUREMENTS OF ENERGY LOSS AND ANGLE SCATTERING OF KEV HYDROGEN IONS IN THE FOILS

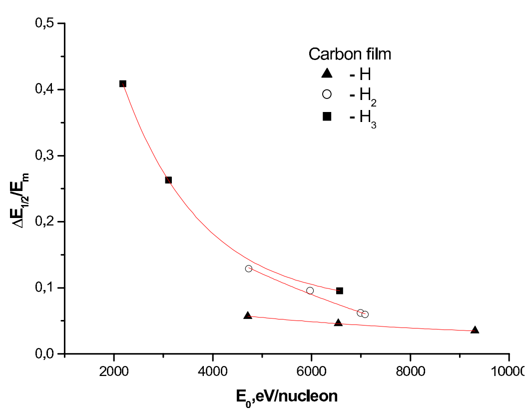
The computer controlled electrostatic energy analyzer of 0.005 energy and ± 1grad. angular resolution was used to measure of energy spectrum and angle distributions of monoenergetic beams (FWHM~ 0.003) of light ions of interest transmitted through the foils. The energy spectrum of H^+ ions with energy of E_0 of 5040eV transmitted through DLC foils 0.6 and 1.4 $\mu g/cm^2$ thick are shown Fig.1 together with simulated data, the latter obtained by means of BCA SCATTER code [6]. Comparison of measured and simulated spectrum revealed the measured thickness of the ultra –thin foils to be larger of factor 50-100% than optimal thickness, mostly due to absorbed gas and onto the foil surface as well as the release agent traces.

As ultimate resolution of the energy/mass analyzer with a foil is apparently limited by energy straggling in the foil , this feature can be conditionally defined as ” energy resolution of the foil ”. A typical dependence of energy resolution of 0.6 μg/cm^2 foil on E_o is shown in Fig.2, demonstrating value less than 3% for $E_o \geq 6$ keV. Also, so called, molecular effect is revealed for H_2 and H^3 ions. Energy straggling in thicker foil with respect to isotopes of fusion interest are shown in Fig.4. Angle distributions of protons escaping different foils reveal capabilities to ensure high detection efficiency for particle analyzing systems even with minor solid angles.



$D_{nom} = 0.6$ μg/cm^2 $D_{eff.} = 1.0$ μg/cm^2 $D_{nom} = 1.4$ μg/cm^2 $D_{eff} = 1.6$ μg/cm^2

Fig.1 Energy spectrum of H^+ ions with $E_0 = 5040$eV transmitted through DLC different foils



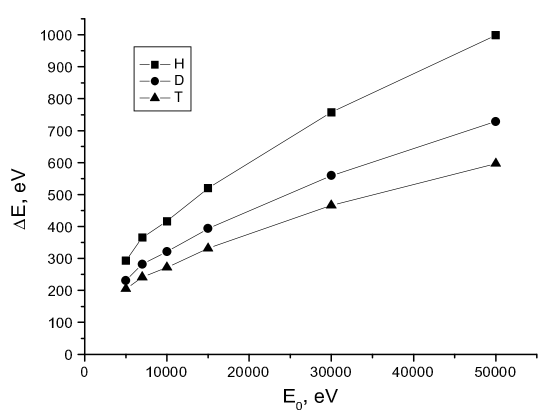


Fig.2 Energy resolution of diamond-like film with $D_{nom} = 30$A (0,6 μg/cm^2)

Fig.3 Energy dependence of ion straggling in the 6 μg /cm ^{2} foil for different ions

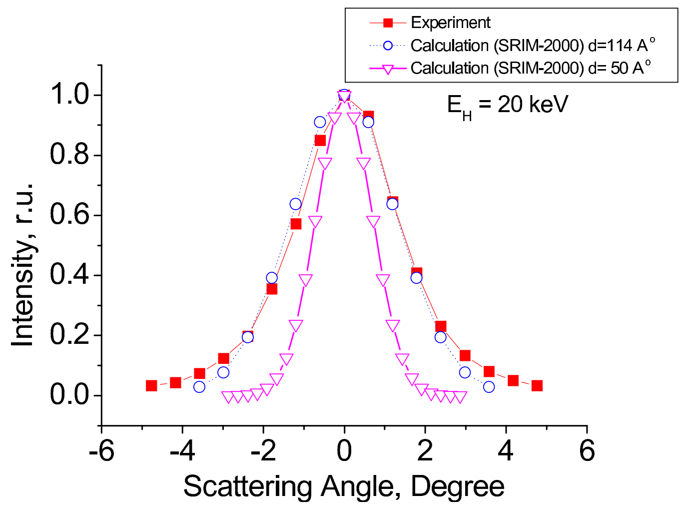


Fig.4 Angle distribution of H^+ ions transmitting through the foils

SUMMARY

1. DLC target foils with minimal thickness of 0,6µg/cm^2 have been developed and applied to variety of particle analyzers for plasma diagnostics.
2. Although effective thickness of ultra-thin DLC foils as measured by energy loss has been shown to be 50-100% larger than nominal one, their energy resolution and angle scattering fit well a new generation of the tools for particle diagnostics.
3. Strong molecular effect for hydrogen ions penetrating through the foils is observed.
4. Developed DLC targets have shown to survive MeV neutron radiation relevant to ITER.

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