Project no: PN-II-ID-PCE-2011-3-0522: « Giga and terra-watt laser interaction with carbon, tungsten and beryllium films »

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Scientific report (Abstract)

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During the year 2013 were performed the following activities:

Were exposed coatings made of Be, W, and C prepared by thermionic vacuum arc method to a dense plasma formed in deuterium and air by focusing high power ultra-short laser pulses. The gas breakdown was possible due to the high laser intensity obtained in the focal spot. Surprisingly, we observed the appearance of periodic striations after firing a relatively large number of laser pulses, between 30 and 300. To the best of our knowledge this is the first demonstration of periodic ridge formation on surfaces by indirect irradiation with a femtosecond laser. Also striations are observed for the first time on a Be surface. Periodic structures are routinely observed when the laser beam is aimed directly at the surface. Here however the laser beam is approximately parallel to the surface, as shown in Fig. 1 (a). The craters created by the plasma on the surfaces were imaged with a scanning electron microscope (SEM) and are shown in Fig. 1 (b). Their shape is elongated, in accordance with the propagation direction of the beam.

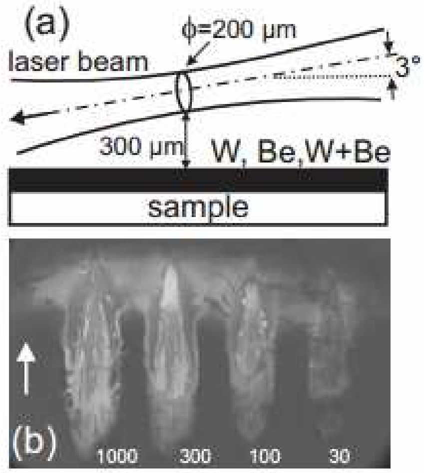

FIG. 1. (a) The laser beam is focused in a spot with diameter φ near the samples coated with Be, W, and C (b) SEM images of craters on the Be surface produced in air after firing 1000, 300, 100 and 30 laser pulses, respectively. The arrow indicates the laser beam direction.

Their size clearly depends on the number of laser pulses: more pulses lead to the formation of larger craters. The samples were produced in-house by coating thin rectangular chips with a size 12×15 mm and made of high density graphite with Be and W using the thermionic vacuum arc. The coatings had a good uniformity and thickness of about 2 μm. For the sample containing both Be and W the weight percentage was 50 − 50%.

Irradiation of the gas near the samples was carried out with single and multiple laser pulses using the 17 terawatt Ti-Saphire system called TEWALAS. The laser system employs the chirped pulse amplification technique for delivering ultra-short pulses. The laser pulses had the following parameters: duration 70 femtoseconds, energy per pulse 6 mJ, repetition rate 10 Hz and p polarization. The beam was focused with a parabolic mirror with 300 mm focal length. The diameter of the focusing spot was about 200 μm resulting in a laser fluence of 19.1 J/cm^2 . The beam made a 3^o angle with the surface of the samples and was focused in their vicinity inside the gas, at a distance of 300 μm from the surface, as shown in Fig. 1(a). The laser beam propagated in vacuum from the compressor to the samples which were inserted in a small target chamber provided with view-ports. The samples were mounted on a movable mechanical support which could be adjusted in the horizontal plane and along a vertical direction. The role of the target chamber was twofold in the experiments: first it allowed the immersion of the sample in different gases at a controlled pressure (including vacuum) and secondly it contained the debris resulted from the interaction of the produced laser-plasma with the surfaces. The Be dust is known to be a health hazard. The experiments were carried out in air at atmospheric pressure and in deuterium at 20 torr. Deuterium was chosen to simulate a tokamak plasma.

The exposed samples of Be, W and C to air plasma are shown in Figs . 2 - 4. We can observe the lamellar pattern of the Be surface consisting in overlapped stacks of a few hundreds of nm in size. This structure is typical for Be coatings obtained by vapor deposition or by plasma arc. This initial structure starts to change morphology in c) and takes a granular aspect. The average size of a granule is in the tens of nanometers range. Due to the prolonged exposure to laser-plasma (i.e. over 300 shots) the granulation becomes more dense and eventually melts forming small droplets at the top of a fiber-like network. No sign of surface arrangement is seen at any time during the shots.

W has a more homogeneous aspect. A pattern of elongated structures starts to emerge after 30 shots. This pattern evolves into a clear and well delimited periodic structure. The surface looks as if composed of aligned rod-shaped structures of hundred of nanometers or even 1 micrometer in length. The average spatial periodicity is $\Lambda = 400$ nm and 270 nm after 300 and 1000 shots, respectively.

The situation is somehow different in D2 atmosphere for all elements (Figs. 5-7) For Be after 1 shot the sample surface has small granules, of a few nanometers in size. After 100 shots, a pattern with rather wide irregular striations is observed on the surface. The average spacing between the striations is $\Lambda \approx 330$ nm. After 300 shots the striations are replaced by large granules which eventually melt and become more homogeneous after 1000 shots. In the case of W immersed in D, only afterabout 300 shots a pattern of striations becomes clearly visible with $\Lambda = 360$ nm. The striations become narrower in where $\Lambda = 290$ nm, after 1000 shots.

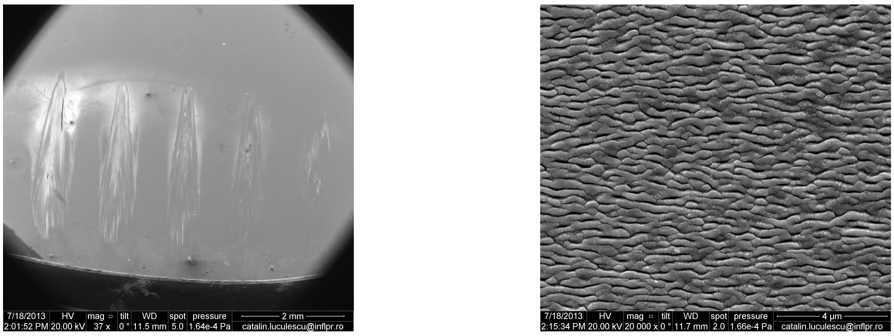

Fig. 2 Morphology of W target after interaction with plasma air plasma

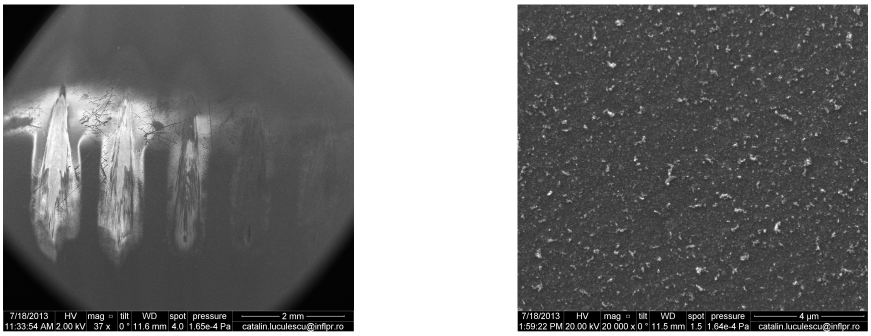

Fig. 3 Morphology of C target after interaction with plasma air plasma

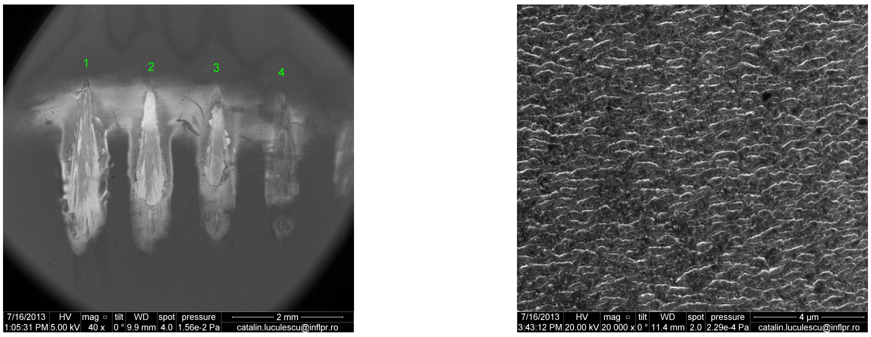

Fig. 4 Morphology of Be target after interaction with plasma air plasma

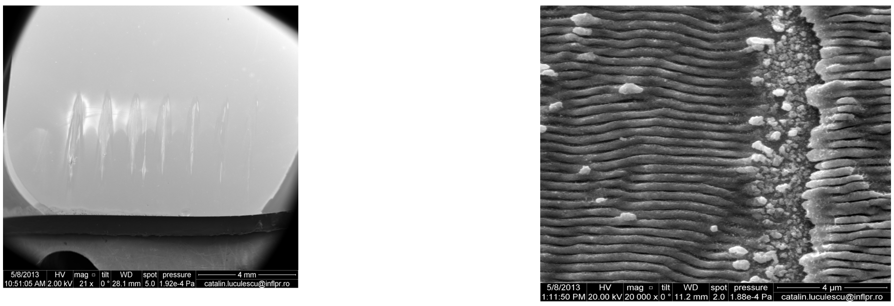

Fig. 5 W target surface morphology after laser indirect irradiation in D2 atmosphere.

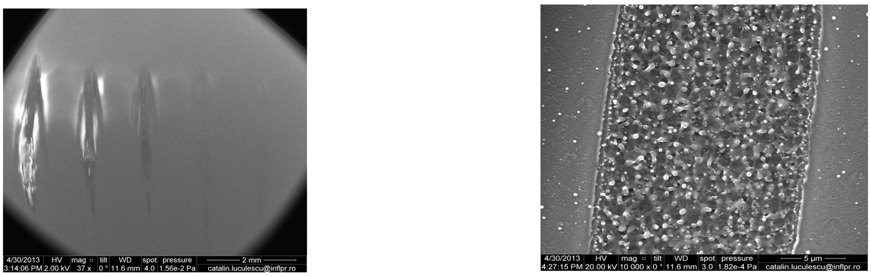

Fig. 6 Carbon target morphology after laser indirect irradiation in D2 atmosphere.

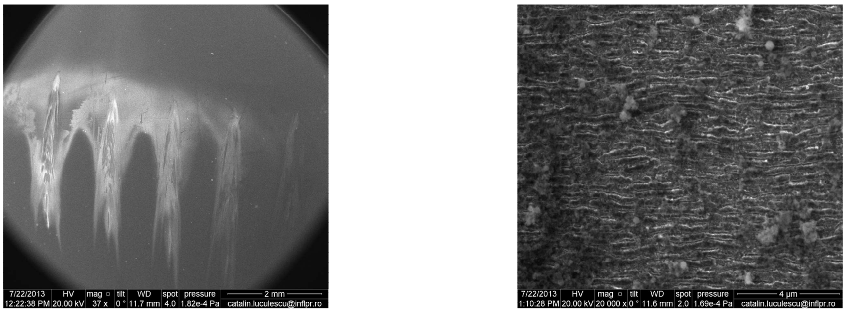

Fig.7 Be target morphology after interaction with plasma produced by laser in D2 atmosphere.

Discussion

The mechanism for surface striations can been explained as the result of interference between the incident laser beam and the surface plasmons although neither Be and nor W have the real part of the dielectric permittivity negative: $\varepsilon W = 5.22 + i19.4420$ and $\varepsilon Be = 2.7 + i2.8$ at $\lambda = 800$ nm. Other factors such as surface roughness and transfer of heat from the plasma to the surface during the ripple formation have to be accounted for.

In conclusion, striations were observed on the surface of samples made of Be, W and C films prepared by TVA method immersed in air at atmospheric pressure and in deuterium at 20 torr after exposure to plasma created by focusing a high power ultra-short laser pulses within the nearby gas, at 300 µm from the surfaces. The morphology of the surface structures is similar to that observed in experiments with direct laser irradiation of the surfaces. This observation could be of interest for the creation of surfaces with variable morphology at the micron level in which periodic structures alternate with regions with no particular structuring.

DISEMINATION

Were published 2 paper in ISI journals and were performed 8 presentations to the International or national conferences.

Nr. Crt.	Titlu articol	An aparitie	Revista	Autori
1	Formation and delamination of beryllium carbide films	2013	JOURNAL OF NUCLEAR MATERIALS	- Mateus Rodrigo - Carvalho Patrícia Almeida - Franco Nori - Alves Luís Cerqueira - Fonseca Micaela - Porosnicu Constantin - Lungu Petrica Cristian - Alves Eduardo
2	NANOSTRUCTURED SINGLE CRYSTAL ZnO NANOWIRE LUMINESCENCE SHIFTING BY ZnO LAYERS	2013	DIGEST JOURNAL OF NANOMATERIALS AND BIOSTRUCTURES	- Marcu Aurelian - Enculescu Ionut - Vizireanu Sorin - Birjega Ruxandra - Porosnicu Constantin

	Titlu	An	Tip Publicatie	Conferinta
1	The behavior of W, C, Be layers in interaction with single and multiple terawatt laser beam pulses	2013	Poster	Advances in Applied Plasma Science, Istanbul, Turkey
2	High Repetition Rate Laser Ablation for VLS Nanowire Grow	2013	Poster	12th International Conference on Laser Ablation (COLA 2013), Ischia, Italy
3	Laser Plume interaction with fusion Interest materials	2013	Poster	12th International Conference on Laser Ablation (COLA 2013), Ischia, Italy
4	Investigations on graphite-diamond transition by high	2013	Poster	Fundamental of laser assisted micro- and nanotechnologies,

	power femptosecond laser irradiation			Tesalonik, Grece
5	Terra-watt laser irradiation effect on fusion materials	2013	Poster	EMRS 2013 Spring Meeting, Strasbourg
6	Laser materials interactions for micro and nano applications	2013	Poster	EMRS 2013 Spring Meeting, Strasbourg
7	Be coatings research for development of fusion plants as clean energy sources	2013	Prezentare Orala	Energy Efficient Buildings and Communities Workshop, Tartu, estonia
8	Deuterium plasma produced by terra-watt laser interaction with Be, C and W	2013	Poster	14th International Conference on Plasma-Facing Materials and Components for Fusion Applications, Jülich, Germany