# FIRST RESULTS WITH COLLECTING PROBES IN U-2M TORSATRON

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The results are presented on a postmortem analysis of the mirror-like SS samples and two glass samples exposed in the Uragan-2M (U-2M) vacuum chamber during experimental campaigns in 2015 and 2016 years. The examination of the samples, after their removal from the chamber, has revealed that all of them were coated with a carbon-containing film of thickness dependent on the sample position. All metal samples were easily cleaned by low energy ions of deuterium plasma, excluding the one located nearby the RF antenna, which was used for RF plasma production.

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## INTRODUCTION

In recent years, as can be concluded from publications [1-4], much effort in experiments at the Uragan-2M torsatron has been given to optimizing the procedure of conditioning the inner vacuum-chamber walls through RF power application. For obtaining information on efficiency of wall cleaning, along with optical spectroscopy of plasma and mass analysis of gas in the course of the conditioning procedure, five stainless steel (SS) mirror-like samples and a couple of glass samples were installed in different poloidal cross sections. Their optical properties were measured before and after they were exposed in the U-2M vacuum chamber for experimental campaigns in 2015 and 2016.

The spectroscopy of plasma during cleaning and working plasma pulses, and the gas analyses testified that the process of cleaning did occur [1-4]. However, after dissembling the vacuum vessel it became clear that the walls were cleaned only partly, and some part of the inner wall surfaces remained black or of temper colors, as can be seen in Fig. 1 of paper [5].

All test samples were found to be coated with the deposit that decreased the reflectance (*R*) of SS samples and the transparency (*T*) of glasses. The reflectance of all SS samples was restored after exposing them in H or D plasmas produced in the DSM-2 stand [6] under electron cyclotron resonance conditions. The results for the *R* restoration are presented in the third part of this paper. The fourth part gives the discussion and conclusive remarks.

## 1. EXPERIMENTAL DETAILS

### 1.1. THE U-2M DEVICE DESCRIPTION

The U-2M device is a toroidal magnetic trap with the $l$=2 $m$=4 torsatron magnetic configuration produced by 16 toroidal and 2 helical coils. Besides, 4 pairs of coils are used to compensate the vertical component of magnetic field produced by helical coils. The major radius of the vacuum chamber is $R$=1.7 m, and its minor radius is $r_c$=0.32 m. At the outer rim of the chamber there are 4 horizontal ports, 20 cm in diameter, which are used for pumping (3 ports) and feeding the frame-type RF antenna. In the same cross sections, but along the inner rim, the ports with diameter 10 cm are located. One antenna was located between coils 1 and 16, and the other – between coils 2 and 3. Throughout the experiments, different regimes of plasma creation and different magnetic configurations were used for wall conditioning and for the RF-produced working discharges.

### 1.2. WITNESS SAMPLES IN U-2M

During the years 2015 and 2016, five stainless steel (SS) mirror samples and two glass samples were exposed in different poloidal cross sections of the Uragan-2M vacuum chamber. Before and after experiments, the reflectance (*R*) of SS samples within the wavelengths of 220 to 650 nm at normal incidence, and the transmission (*T*) of glass samples in the range 400 to 650 nm were measured.

The positions of all samples are schematically shown in Fig. 1.

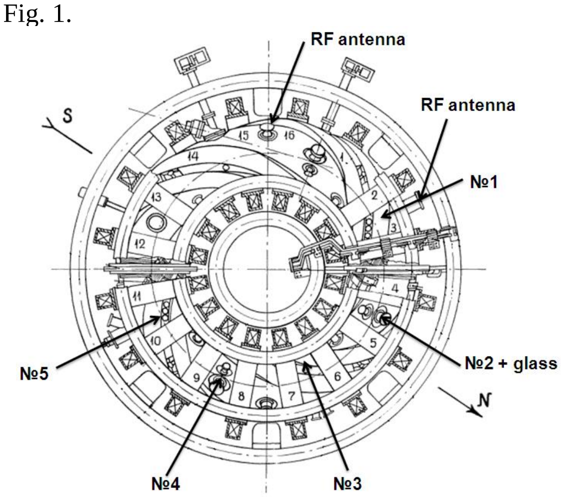



*Fig. 1. Top view of U-2M with locations of collecting probes*

All samples, excluding one, were oriented horizontally and placed at the ‘bottom’ of the vacuum chamber; and one sample, installed in the port located at the inner torus perimeter, was oriented vertically. After the samples were taken out from the U-2M vacuum vessel, all of them appeared coated with some deposit, what has resulted in the reflectance degradation reduction. To clean the samples, they were exposed to low energy ions of hydrogen or deuterium plasma produced under electron cyclotron resonance (ECR) conditions in the DCM-2 stand [6].

One SS sample (№ 1) was fixed between toroidal coils 2 and 3, in the nearest vicinity of the frame-type antenna made of stainless steel (left photo of Fig. 1 in [5]). The other SS sample (№ 2) was placed between coils 4 and 5 together with two glass samples. Half the surface of one glass sample was protected from plasma by a thin SS foil. Locations of other samples were between coils 6-7 (№ 3, oriented vertically), 8-9 (№ 4), and 10-11 (№ 5).

## 2. EXPERIMENTAL RESULTS

After removal from the U-2M chamber, the samples were exposed to low-temperature hydrogen or deuterium plasma produced in the DCM-2 stand. During exposure, the samples were fixed in a grounded holder, i.e., without supplying negative potential for ion acceleration ($V_{acc}$=0). After a short (20 min) treatment, all the SS samples, except № 1, were found to be fully cleaned. As our previous experience has shown, the ease of deposit removal means that the film consists practically of pure carbon. At the same time, the cleaning of sample №1 to the stage of initial reflectance, has required much longer exposures to D plasma ions: $V_{acc}$ = 0 V – one hour, $V_{acc}$=-60 V – one hour, $V_{acc}$=-300 V – one hour. A high resistance to removal of the contaminating deposit on the sample is an evident indication that the deposit contains some portion of metallic component. Something like that was observed for a similar sample exposed in the Large Helical Device [7], when for effective cleaning of the sample higher-voltage accelerating ions to the sample surface were needed during the cleaning procedure in the DSM-2 stand.

The results of exposure and cleaning of three samples exposed between coils 2-3, 6-7, and 8-9 are presented in Fig. 2. The plots for the other two samples (№ 3 and № 5) are not shown as they are very much similar to those in Fig. 2,c. Fig. 3 demonstrates the difference $\Delta R$ between the reflectances at $\lambda$=500 nm, measured when the exposed samples were fully cleaned and just after they were withdrawn from the U-2M chamber (with the deposition that appeared during exposure in U-2M).

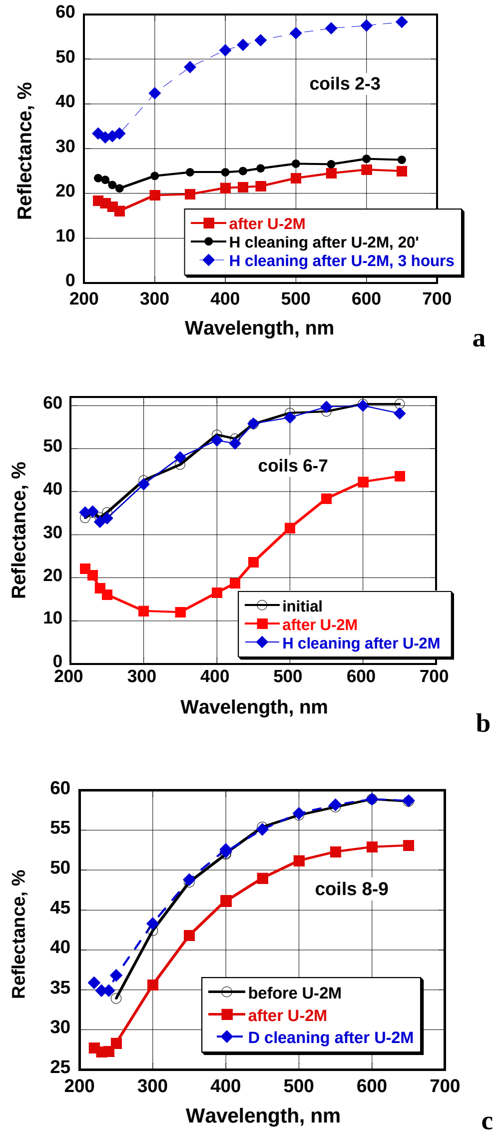



*Fig. 2. Drop and restoration of reflectance of three SS samples exposed in locations as indicated in legends*

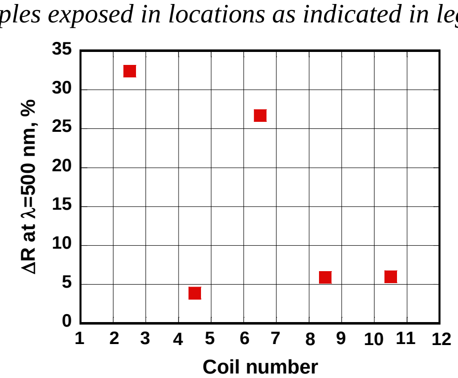
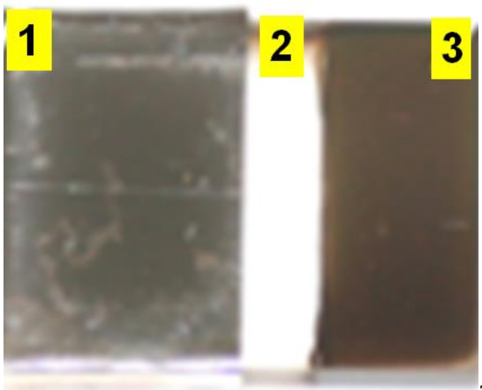


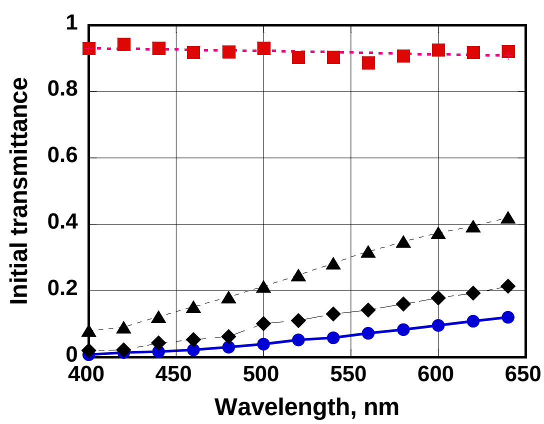

*Fig. 3. Difference $\Delta R$ between initial reflectance (i.e., fully cleaned samples) and reflectance just after samples were withdrawn from the U-2M chamber*

Fig. 4,a gives the photo of one of the glass samples (exposed between coils 4 and 5) taken right after it was withdrawn from the U-2M chamber. The figures in the photo indicate: 1 – the SS foil, which partly protected the glass sample; 2 – the part of sample that was protected by the SS foil during exposure and, therefore, remained clean and transparent; 3 – the part of glass sample that was open to plasma and became coated by an almost fully opaque deposit.

The exposure effect on the similar glass sample exposed nearby in the U-2M and the results of its cleaning by ions of Ar and D plasmas are presented in Fig. 4,b. The first step of cleaning included four exposures: one in the Ar plasma without ion accelerating potential (75 min) and three – in the D plasma with a negative potential of -100 V for acceleration of ions to the sample surface (total time 2 hours). In the second stage the ion energy was increased up to 300 V (15 min). As is seen, these cleaning procedures were insufficient for the recovery of transmittance of the glass.



a



b

*Fig. 4. Photo of glass sample exposed in U-2M vacuum chamber (a) and its transmittance (b): ■ – before installation in U-2M vessel; ● – after exposure in Uragan-2M; ♦ – first step of cleaning procedures; ▲ – second step of cleaning*

## 3. DISCUSSION

The use of long time exposed samples with postmortem analysis of their surface is a simple technique that enables one to judge about effectiveness of an overall conditioning of the vacuum chamber walls. In the case of U-2M experiments, the research data of papers [1-5] suggest that the cleaning process used previously has affected only some part of the internal surfaces of the vacuum volume. The other part remained to be coated with a contaminating deposit, or on the contrary, became coated in the course of conditioning procedures, as it happened with SS and glass samples exposed during 2015 and 2016.

A high resistance to cleaning of the contaminating deposit on the sample exposed in the nearest vicinity of RF antenna is an evident indication that the layer occurring on its surface contains some metal component, though no analysis of the deposit was performed. This conclusion can be made basing on the results obtained when analyzing the results of exposure of similar SS mirror samples in the Large Helical Device. In that case, the necessity to apply higher voltage during long-time cleaning (in DSM-2 with D plasma) of one of three samples [7] was owing to ~40 % metal portion in the composition of the deposit found on the sample exposed in the divertor area. Those data were obtained by the Rutherford backscattering (RBS) technique with the use of a 1.5 MeV $He^+$ ion beam.

The other facts in qualitative support of this assumption can be found in paper [8] and Ph. D. Thesis [9], where a detailed study of the effects of different metal dopants on the carbon film resistance to sputtering by D ions was presented. A noticeable decrease in the sputtering rate of metal-doped carbon was observed as early as at metal concentrations (Ti, V, Zr, W) of ~1 % [9].

It is appropriate to note here that the data clearly indicating that just the RF antenna is responsible for 'sawing' of the immediate surrounding with material of its coating (TiN) were obtained long ago during experiments at the Uragan-3 torsatron, when the RF antenna coated with a TiN film was explored [10]. The Ti presence was found in the deposited film only on those collecting probes that were exposed in the nearest vicinity of the RF antenna used for plasma production and heating.

## CONCLUSIONS

The first data obtained with collecting probes support the inference following from the analysis of the works devoted to wall conditioning in the U-2M torsatron, and cited in the Introduction. Namely, in spite the fact that the process of wall cleaning is definitely taking place, not all inner surfaces are involved in this process. Moreover, as the collecting probe data show, there are some parts of the wall where the opposite process, viz., the deposition of contaminating layer takes place. The main component of the deposited layer appeared on the probes exposed far from RF antenna is carbon, but on the probe nearest to the antenna the deposited layer is largely composed of metal.

The collecting-probe method is 'passive' and gives no way to control *in situ* the process of wall cleaning. Therefore, other methods to control the cleaning process have to be used when performing wall conditioning in the machine. One possibility to control the efficiency of cleaning of the carbonized film predeposited on a metal probe has been described and discussed in [11].

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### ПЕРВЫЕ РЕЗУЛЬТАТЫ ПО ИСПОЛЬЗОВАНИЮ СОБИРАЮЩИХ ЗОНДОВ В ТОРСАТРОНЕ U-2M

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Представлены результаты анализа поверхности образцов зеркал из нержавеющей стали и двух стеклянных образцов, экспонированных в вакуумной камере установки Ураган-2М в течение двух экспериментальных кампаний (2015 и 2016 гг.). После изъятия образцов из вакуумной камеры было обнаружено, что все они покрыты углеродсодержащей пленкой, толщина которой зависит от положения образца. Все металлические образцы были легко очищены от загрязняющего слоя низкоэнергетичными ионами дейтериевой плазмы, за исключением образца, располагавшегося вблизи ВЧ-антенны, которая использовалась для создания плазмы.

### ПЕРШІ РЕЗУЛЬТАТИ ЩОДО ВИКОРИСТАННЯ ЗБИРАЮЧИХ ЗОНДІВ У ТОРСАТРОНІ U-2M

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Представлено результати аналізу поверхні зразків дзеркал з нержавіючої сталі і двох скляних зразків, експонованих у вакуумній камері установки Ураган-2М протягом двох експериментальних кампаній (2015 і 2016 рр.). Після вилучення зразків з вакуумної камери було виявлено, що всі вони покриті вуглецевмісною плівкою, товщина якої залежить від положення зразка. Всі металеві зразки були легко очищені від забруднюючого шару низькоенергетичними іонами дейтерієвої плазми, за винятком того, що розташовувався поблизу ВЧ-антени, яка використовувалася для створення плазми.