THE ADVANCED NANOSTRUCTURE STEEL MODIFICATION BY GAS IONS BEAMS

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Abstract

New construction materials are under developing for the nuclear energy sector. They will provide energy production, store and transportation with high efficiency and ecology safety. The nanostructures steels like a consolidation oxide dispersion strengthened (ODS) as well as ferritic-martensitic steel (for example EK-181) are the most promising materials for new generation of nuclear reactors. The experimental program for investigation of the steel nanocluster generation and growth under ion beam irradiation is ongoing in ITEP at the accelerator complex "Heavy ion prototype-1" (HIPr-1). The duoplasmatron ion source provides gas ion beams for experimental program. The source installation and it's power systems development are presented. As well the results of charge state distribution measurements for nitrogen ion beam generated by the duoplasmatron and the first results of ODS materials irradiation by gas ions are described and discussed.

INTRODUCTION

The changes in chemical composition of structural steels which occur under irradiation can cause changes in their mechanical characteristics. To investigate the steel structure changes under irradiation, in ITEP experimental works for structural materials irradiation by metal ion beams are carried out since 2007 [1]. However, the investigation of materials irradiated by both gas ion beams and combination of gas and metal ion beams can significantly enlarge the experimental potential of ITEP research program.

At the accelerator "heavy ions-prototype-1" (HIPr-1) a gas ion source duoplasmatron was installed, tested, tuned and put under operation. The procedure of materials irradiation with gas ions was tested. Nitrogen ion beam with a current of 150 mA was obtained at the outlet of the injector. The results of charge state distribution measurements for nitrogen ion beam generated by the duoplasmotron as well as the first experimental data obtained for ODS steel irradiated by the nitrogen beam are presented and discussed.

EXPERIMENTAL FACILITY

Experiments on the structural steels modification are performed at the accelerator TIPr-1, which shown on figure 1. Injector system (1) consists of ion source, extraction system and accelerator tube with high voltage up to 100 kV. The beam current at the injector output is measured by beam transformer (2). The experimental chamber (3) is used for steel samples irradiation by low-energy ion beams. Electrostatic lenses (4) provide beam matching with the input to RFQ (5). The chamber (6) has a beam detector for accelerated beam current measurements. Three magnetic quadruples (7) forms at the targets the beam profile needed for experiments. In chamber (8) the target assembly for material samples irradiation by the ion beam accelerated in TIPr-1 is installed. The target construction enables the irradiation experiments with samples heated to the temperature up to 700ºC.

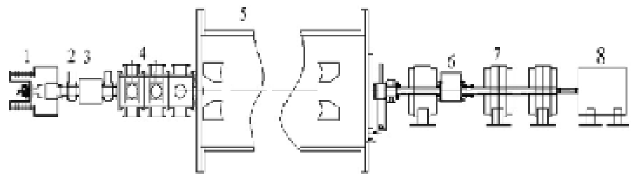

Figure 1: Scheme of accelerator TIPr-1.

Duoplasmatron, which is a regular source for proton beam generation at the injector I-2 at ITEP, was installed in TIPr-1 injector system. The pulse valve mounted at discharge chamber output significantly reduces the gas load in the injector and enables the cold cathode operation mode [2]. A system of the power supply for duoplasmatron was developed. It provides the production of an ion beam with a duration of 60 microseconds and a pulsce repetition rate of 1/3 pps.

The power supply circuit of the ion source is shown at figure 2. The main elements of this circuit are a pulse discharge generator (PDG), a power supply (PSIV) for the inlet valve; power supply for duoplasmatron magnet (PSM). This circuit located on the high voltage platform.

TEST OF ION SOURCE WITH NITROGEN BEAM

Duoplasmatron was tested under operation with nitrogen ion beam. The time-of-flight method was used for charge state distribution (CSD) measurements of nitrogen ion beam generated by duoplasmatron [3]. CSD and beam current were measured for two different discharge currents: I_{arc}=213 A and I_{arc}=173 A. The CSD behavior during the beam pulse for discharge current of 173 A is shown in Figure 3. The measured distribution of different ions in total beam current are shown in Table 1.

ISBN 978-3-95450-170-0

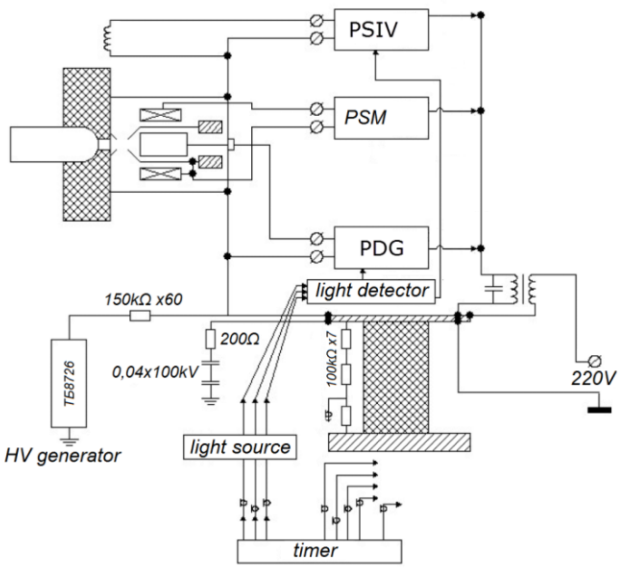

Figure 2: Circuit of duoplasmatron power supply.

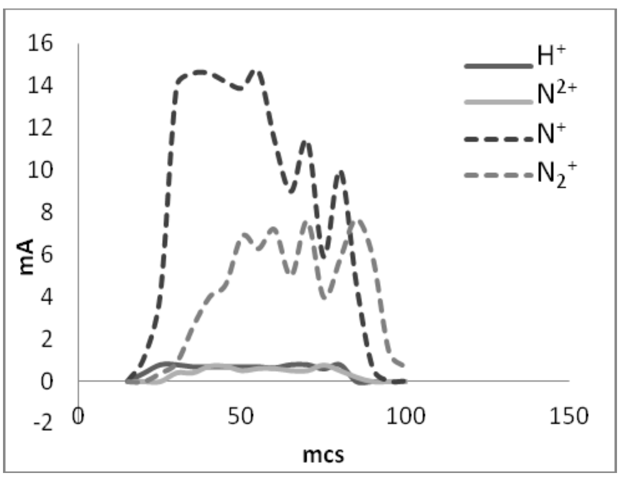

Figure 3: Charge ion distribution in duoplasmatron beam.

Table 1: Charge distribution of the ions in the beam from duoplasmatron.

Ions	I_{arc}=173 A	I_{arc}=213 A
H^+	4,0%	11,5%
N^{2+}	1,4%	4,9%
N^+	63,2%	73,1%
N_2^+	31,4%	10,5%

RESULTS

For simulation experiments, the samples in the form of needle with tip thickness of about hundred nanometers were used. They were mounted in a chamber (p.3. Figure. 1) at the injector output and were adjusted so that the needle tips are located close to the centre of the beam axis. During experiemnts the pressure in the chamber was $P=5\cdot10^{-6}$ torr. The ion source was adjusted to the operation with a current density of ~1 mA/cm^2. The oxide dispersion strengthened (ODS) Eurofer steel and ferritic-martensitic precipitation-aging steel EK-181 were used for experiments. Their chemical compositions before irradiation are given in Table. 2. Two sets of samples from those materials were irradiated by different beams. One of them was irradiated by the titanium ion beam and another one by nitrogen ion beam. The flux of 10^{15} particles/cm^2 for both experiments was achieved. The research of the irradiated samples were performed on an optical tomographic atom probe microscope [4].

Table 2: Chemical compositions before irradiation, at %.

	Eurofer ODS, at %	EK-181, at%
Cr	9.65	11.9
Mn	0.38	0.95
Si	0.16	0.73
C	0.51	0.64
N	0.03	0.16
O	0.37	-
V	0.38	0.31
Y	0.25	-

The peaks corresponding to the evaporated Ti^+ and N^+ ions were found in the mass spectrum of the irradiated samples. According simulation the concentrations of these elements in irradiated samples should be increased by 0.2 at. %. Data with experimental values are shown in Table 3. Comparing Tables 3 and 2 one can see that experimental data for nitrogen don't correlate with the calculated ones. The discrepancy between the results may be due to the migration of the implanted nitrogen from the irradiation zone to the sample surface.

It is necessary to note that the clusters in the samples under nitrogen beam irradiation not changed however clusters in the samples irradiated by Ti beam changed significantly.

Table 3: Chemical compositions after irradiation.

The test sample	Chemical Element	Concentration after ion irradiation to a dose of 10^{15} particle/cm^2	Estimated value of the concentration particle/cm^2
Eurofer ODS	N	0.06±0.01	0.2
EK-181	N	0.04±0.01	0.2
Eurofer ODS	Ti	0.23±0.07	0.2
ЭК-181	Ti	0.21±0.05	0.2

ISBN 978-3-95450-170-0

CONCLUSION

The gas ions source (duoplasmatron) was installed at the accelerator HIPr-1, to provide the investigation of material modification under gas ion implantation into the prospective steels for nuclear reactor manufacture. The power supply circuit, gas pipeline and related tools were developed for the ion source, to provide gas ion beam generation with pulse length of 60 µs and repetition rate of 1/3 pps and beam current up to 100-200 mA. Nitrogen ion beam with a current of 150 mA –was generated and used for the experiments.

The charge state distribution of the nitrogen ion beam during the discharge time in duoplasmatron was measured by the time-of-flight method.

The samples of EK-181 and ODS were irradiated by nitrogen ion beam with energies up to 60 keV. Results were compared with the ones obtained after the titan ions implantation.

For nitrogen beam, irradiation changes in chemical composition of the samples did not coincide with the simulated ones thanks to the migration of implanted nitrogen atoms to the sample surface. As a next step we plan to carry out the irradiation of the same steel samples first by the titanium beam and then by the nitrogen beam.

REFERENCES

[1] Rogozhkin S.V., Kulevoy T.V., Iskandarov N.A., Orlov N.N., Chalykh B.B., Aleev A.A., Grachev N.Y., Kujbeda R.P., Nikitin A.A., Fertman A.D., Shishmarev V.B."Simulation experiment on study in the radiation resistance of advanced ferrite-martensite steel hardened by disperse inclusions". Atomic Energy. 2013. T. 114. № 1.C. 14-20.

[2] V.A Batalin, A.A. Kolomiec, B.K. Kondrat'ev, R.P. Kujbeda. “Duoplazmatron s holodnym katodom dlja inzhektora linejnogo uskoritelja protonov.” PTJE №2 1975 (In Russian).

[3] Batalin V.A., Kondrat'ev B.K., Turchin V.A. “Ionno-opticheskaja sistema istochnika tjazhelyh ionov dlja vremja-proletnyh izmerenij”.\\ PTJE, N 4, 1987g., str.34. (In Russian).

[4] S.V. Rogozhkin, A.G. Zaluzhnyj, A.A. Aleev, A.V. Karpov, O.N. Makeev “Tomograficheskaja Atomno-zondovaja mikroskopija nanoctrukturirovannyh materialov” ISBN 5-7262-0633-9. NAUCHNAJA SESSIJA MIFI-2006. Tom 9 (In Russian).