REPRODUCIBILITY OF TRITIUM GENERATION FROM NUCLEAR REACTIONS IN CONDENSED MEDIA

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ABSTRACT

In this work, based on the proposed model, the results of practical activity in the nuclear reactions in condensed media (NRCM) field are given. We also specify the requirements for these reactions and for the selection of the materials to be used for the purpose of obtaining good reproducible results on tritium generation. In addition, we discuss the limits of the main parameters of the ion bombardment by using a glow discharge as an example.

INTRODUCTION

The nuclear reactions in condensed media (NRCM) have been studied more in breadth rather than in depth. As a result, at present reliable results of investigations of practically all types do not much exceed the background. The powerful glow discharge system, that we have used for the similar NRCM investigation, have allowed us to obtain reliable data on tritium and neutron generation and element transmutation [1]. One of the main features of our glow discharge system is the use of higher plasma-generating gas pressures which makes it relatively easy to obtain high flux densities for the deuterium ions bombarding the target sample (cathode).

EXPERIMENTAL PROCEDURE

The design of the plasma-discharge unit and the experimental procedure on tritium detection is similar to that described in [1]. Plates, pipes having the wall of 0.2-5.0 mm thick, and rods having 2-20mm in diameter were used as samples. The samples were mainly made of tungsten and niobium.

DISCHARGE PARAMETER EFFECT ON TRITIUM GENERATION

ION ENERGY. According to the estimated calculations (Table 1, [1]) the optimal interaction energy depends on the matrix material. This energy is about 30 eV for the deuterium medium and reaches 5 keV for heavy elements of Mendeleyev's periodic table. The lower energy range is verified by Fig. 1 [1] and Table 2 in this article. In Table 2 one can see that, when operating in the near-threshold energy range, the tritium generation efficiency (the nuclear interaction coefficient) decreased by about an order of magnitude as a result of some ion energy decrease, in spite of the fact that the current density has increased by a factor of 30. Perhaps, the rapid decrease in the tritium generation efficiency when the ion energy exceeds the model predictions (Fig. 1, [1]) is connected with the fact that according to the experimental conditions the energy increase is accompanied with a density decrease.

Table 1. **NRCM** Efficiency versus Discharge Parameters

Material	Discharge Parameters					Nuclear interaction coefficient, atom.ion^{-1}	Tritium flux. aton.s^{-1}
	Voltage, V	Current density, A.cm^{-2}	Temperature, K	Pressure, 10^3 Pa	Time, h		
1	2	3	4	5	6	7	8
Nb	1560	0.05	1070	20	22	$5.3 \cdot 10^{-13}$	$2.6 \cdot 10^{6}$
Nb	1900	0.10	1270	30	23	$5.0 \cdot 10^{-13}$	$2.7 \cdot 10^{6}$
Nb	760	0.10	1170	12	162	$3.8 \cdot 10^{-13}$	$1.0 \cdot 10^{7}$
Nb	1800	0.20	1670	40	8	$2.5 \cdot 10^{-12}$	$1.7 \cdot 10^{7}$
Nb	2100	0.30	1770	50	6	$3.1 \cdot 10^{-12}$	$2.6 \cdot 10^{7}$
Nb	1080	2.00	1670	20	6	$7.1 \cdot 10^{-11}$	$0.8 \cdot 10^{9}$
Nb	1000	2.00	1670	40	8	$1.2 \cdot 10^{-10}$	$0.9 \cdot 10^{9}$
Nb1)	820	10.00	1170	20	60	$6.8 \cdot 10^{-11}$	$1.7 \cdot 10^{9}$
$\mathrm{W}^{[111]}$	640	0.08	1470	10	20	$6.4 \cdot 10^{-14}$	$0.7 \cdot 10^{6}$
$\mathrm{W}^{[111]}$	640	0.08	1270	10	18	$7.3 \cdot 10^{-14}$	$0.7 \cdot 10^{6}$
W2)	1550	0.20	900	30	44	$1.1 \cdot 10^{-13}$	$1.5 \cdot 10^{6}$
W	1200	0.30	1670	40	42	$2.8 \cdot 10^{-13}$	$4.2 \cdot 10^{6}$
W	1080	1.00	3500	50	7	$4.8 \cdot 10^{-12}$	$4.5 \cdot 10^{7}$
W	800	1.50	3600	65	6	$8.1 \cdot 10^{-12}$	$8.4 \cdot 10^{7}$
W1)	720	10.00	1500	21	115	$9.1 \cdot 10^{-12}$	$2.5 \cdot 10^{6}$
W	800	1.00	1670	20	8	$3.0 \cdot 10^{-11}$	$2.5 \cdot 10^{8}$
W	1150	8.00	1670	40	20	$2.5 \cdot 10^{-11}$	$1.7 \cdot 10^{8}$

1) - Discharge in the magnetic field
2) - Pulsed discharge

ION FLUX. The nuclear interaction coefficient versus the current density at a slight deviation of the rest of the parameters can be determined from Table 1. The current density increase in the discharge can be optionally accompanied by the NRCM efficiency increase if it results in decreasing the energy of the deuterium ions bombarding the target. In particular, this effect is observed under higher pressures in the near-threshold energy range (See Table 2). According to Table 1, one can consider the current density about 500 Amp.m-2 to be the lower limit to detect the NRCM reliably.

Table 2. **NRCM** Efficiency versus Discharge Parameters at Higher Pressure.

Material	Discharge Parameters					Nuclear interaction coefficient, atom.ion^{-1}	Tritium flux. aton.s^{-1}
	Voltage, V	Current density, A.cm^{-2}	Temperature, K	Pressure, 10^3 Pa	Time, h		
1	2	3	4	5	6	7	8
W	900	0.2	1070	20	22	$9.4\cdot10^{-13}$	$1.1\cdot10^{7}$
W1)	1300	0.6	1170	40	46	$3.2\cdot10^{-13}$	$4.0\cdot10^{6}$
W1)	2540	2.0	1170	80	115	$1.0\cdot10^{-13}$	$1.5\cdot10^{6}$
W1)	1380	6.0	1170	120	52	$1.6\cdot10^{-13}$	$2.5\cdot10^{6}$

1) - pulsed discharge

PRESSURE. The plasma-generating gas pressure has an effect on the hydrogen solubility and the mean energy of the ions bombarding the surface. The pressure increase results in increasing the hydrogen concentration in the target and decreasing the mean ion energy. The normal current density in the discharge is proportional to ~ P2 under normal and abnormal conditions that are close-to-normal. Therefore, it is difficult to obtain the required hydrogen atom concentration in the matrix and to provide a sufficient current density under the specific pressure optimum. And under higher pressures the increase in the current density and concentration cannot compensate for the NRCM efficiency decrease by reducing the energy of the ions bombarding the target (Fig. 1). In Fig. 1, one can see that the pressure optimum for molybdenum, tantalum, and tungsten according to the maximum value of the nuclear interaction coefficients is within (20 to 40) x 1000 Pa. For niobium, the optimum is most probably shifted down to (10 to 30) x 1000 Pa.

TARGET TEMPERATURE. As the target is bombarded by the deuterium ions having a minimum energy of tens of electron volts (hundreds of thousands of Kelvins), the target temperature should have a slight direct effect on the NRCM efficiency. However, the temperature has a direct effect on the hydrogen concentration in the target. Therefore, for the hydride-generating materials (niobium, zirconium, palladium, etc.) temperature increases should result in a tritium generation decrease and for the nonhydride-generating materials (nickel, molybdenum, tungsten, etc.) - in tritium increase. The nonhydride-generating materials have the optimal temperature about 0.5 Tmelt (1300-1800°K for molybdenum and tungsten), because temperature increase is accompanied by the exponential thermionic emission increase. The hydride-generating materials also have the optimal temperature.

TARGET MATERIAL AND SURFACE STATE. According to our model [1] two deuterons of Coulomb potential are efficiently shielded by the excited atoms of the target matrix, most probably as a result of some additionally released electrons, which (the deuterons) can generate as quasi-plasma. For example, see reference [2]. Therefore, one can come to two important conclusions. First, the heavy elements will have a higher shielding efficiency because their atoms have more electrons at a lower binding energy except for K-cladding. Secondly, the NRCM area won't exceed the value of the projected ion run path in the condensed media; about (10-1) nm for the energies of about 1 keV. In this case different surface compositions with lighter elements, e.g. carbides, nitrides or oxides, will considerably cover the NRCM efficiency both by decreasing the hydrogen solubility in the near-surface layer and by reducing the efficiency of Coulomb potential shielding. It is verified by the experiment that where the reverse deuterium countercurrent flows though the wall of the tight sample the foreign material film formation was inhibited at the surface facing the plasma (Table 3).

Table 3. **NRCM** Efficiency versus Deuterium Flux Through the Sample Wall.

Material	Discharge Parameters					Nuclear interaction coefficient, atom.ion^{-1}	Tritium flux. aton.s^{-1}
	Voltage, V	Current density, A.cm^{-2}	Temperature, K	Pressure, 10^3 Pa	Time, h		
1	2	3	4	5	6	7	8
Zirconium	Steady state	820	1070	15	6	$1.7 \cdot 10^{-12}$	$1.1 \cdot 10^{7}$
Zirconium	Deuterium *)	950	1270	30	5	$1.4 \cdot 10^{-11}$	$1.4 \cdot 10^{8}$

*) countercurrent flow, $\Delta P = 60 \cdot 10^3$ Pa

CONCLUSIONS

For the simplest reproducibility of the above-mentioned results one can use the glow discharge of direct current at a deuterium pressure of about 20 x 1000 Pa. One can use either rods having 5-10 mm in diameter or plates 0.2-1.0 mm thick made of molybdenum, tungsten, or niobium as a target sample (cathode). The sample temperature should be kept within 1100-1500°K at the expense of the glow discharge power. In this case forced cooling isn't required. The discharge voltage within 600-1000 V can be additionally controlled by the distance between anode and cathode. Current also depends on the sample dimensions and cooling degree. The value of 1-5 A will be sufficient. We think that if one follows these recommendations, the tritium will be generated at a level of 1,000,000-10,000,000 atoms per second when the efficiency is at least 10 - 14 atoms per ion. Following the above recommendation we have made over 60 experiments during the last year. In all the experiments the tritium fluxes were at a level of 10^{-6} to 10^{-7} atoms per ion, when the nuclear interaction coefficients were at least 10^{-14} atoms per ion for such target materials as niobium, molybdenum, and tungsten.

REFERENCES

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