SHOCK ALLOYING OF METALS BY CUMULATIVE PLASMA STREAMS

L.I. Ivanov[1], A.I. Dedyurin[1], I.V. Borovitskaya[1], O.N. Krokhin[2], V.Ya. Nikulin[2], E.N. Peregudova[2], S.N. Polukhin[2], A.A. Tikhomirov[2], Yu.S. Avraamov[3], A.D. Shlyapin[3]

[1]A.A. Baikov Institute of Metallurgy and Material Sciences of RAS, Moscow, Russia;
[2] P.N. Lebedev Physical Institute of RAS, Moscow, Russia;
[3] Moscow State Industrial University, Moscow, Russia

The report presents the investigation of a possibility of an application of pulse concentrated energy fluxes for the creation by shock alloying method of pseudo-solid solutions of metals, which interact chemically with each other neither in solid nor in liquid states. As an example of such compounds a system W-Cu was chosen. The experiments were conducted by use of plasma focus facility PF-4 (Installation "TYULPAN") in Lebedev Physical Institute. In the work it was found that the copper plate was welded with the high degree of adhesion to tungsten. The nature of the penetration of chemically neutral atoms of Cu in material of a target (W) is connected probably with two processes – the energy transfer to atoms from concentrated pulse fluxes of energy and the initiation of shock waves and their propagation in the target material.

PACS: 52.77.-j; 52.59.Hq

1. INTRODUCTION

In an industry at the manufacturing of constructing elements operating in extreme conditions there is a need of creation of compound of diverse materials (for example, such as W-Cu) which interact chemically with each other neither in solid nor in liquid states.

In the given work we offer a new method of compound of such materials – method of shock alloying of metal by cumulative streams generated in plasma focus installation. As an example of shock alloying of metals the system W-Cu was chosen. Earlier similar compounds, or pseudo-solid solutions, could be created or direct ion implantation, especially widely used in a semi-conductor industry [1], or so-called implantation of feedback, which essence consists in drawing on a surface of a material of a layer of an element which is necessary to implant with subsequent or simultaneous "hammering" of atoms of this element by high-speed ions of chemically neutral gases [2,3]. The basic imperfection of this method is necessity of long duration of time to achieve of given concentration of an introduced element in a superficial layer of a material of a matrix. In 70 years of the last century at the research of the influence on an aluminum surface of moving with speed of the order 8 km /s micro-particles of chromium by a method of autography was shown, that Cr penetrates into aluminum on the distance essentially exceeding visible superficial craters [4]. Such experiments have served as an example of the shock alloying of materials and have formed the basis idea to realize such process with the help of high power pulse of plasma flows generated, for example, in installations of a plasma focus type (PF). Besides, at the influence of the concentrated pulse flows of energy on a material nonlinear shock waves are arisen, the velocity of propagation of which in a material exceeds the velocity of a sound, and their dissipation on elements of crystal structure creates interstitial atoms and vacancies, which influence on the depth of the penetration of the introduced atoms and the their coagulation. Besides, shock wave can promote introduction of implanting atoms on the large distances from a surface. Such phenomena was observed in [5], where the atoms of deuterium at a pulse impact of deuterium plasma on vanadium have penetrated on depth of 2 mm at the room temperature, forming visible gas porous, that essentially exceeds the depth due to the thermal diffusion..

2. EXPERIMENTAL INSTALLATION AND RESULTS

In these experimental researches the installation "Tyulpan"of Lebedev Physical institute was used [6, 7]. The stored energy in capacitors of the installation was 4 kJ. The discharge chamber was filled by deuterium up to pressure of 1…2 Torr. The important property of such installations is the formation in it of a cumulative plasma stream with density about 10^{18} cm^{-3}. This stream moves along an axis of the installation from the anode. The velocity of such stream depends on the geometry of electrodes, sort of gas in the chamber, and also from distance from the anode. In our case the velocity of a cumulative stream in the area of the position of researched samples was $(2…4) \cdot 10^7$ cm/s. Time duration of the influence of a plasma pulse on a sample was no more than 50 ns. Temperature of plasma was about one million degrees that results in the large gradients of temperatures in an irradiated sample. Energy flux density of plasma pulse on a target was in the range $10^8…10^{10}$ W/cm^2. Time interval between pulses 3 mines.

The irradiation of samples was carried out in two modes of operations PF with usual polarity of a voltage on electrodes of the installation, when on the central electrode (anode) - plus and with inverse polarity. In the first case the generation of the accelerated particles (electrons and deuterons) was observed. In the experiment we specially used the initial conditions in the discharge chamber when the flow of accelerated particles on a sample was insignificant - no more than 10^{12} particles/cm^2. In case of inverse polarity of voltage on electrodes of installation the flow of accelerated deuterons was directed from a target and its intensity on some orders less, than in the first case. In a course of research the special role of accelerated deuterons in the transfer of energy to atoms of Cu due to elastic collisions was not revealed. Copper has penetrated in tungsten irrespectively of polarity of a voltage on electrodes PF.

It is necessary also to note, that the anode of PF was made from an alloy W-Ni, that excluded the penetration of Cu in the plasma stream, which, as a rule, are present in plasma, if the anode of PF is made of copper (as it is usually made). The plate of W by thickness of 3 mm covered by a foil of Cu (thickness 300 μ) was placed on the cathode of PF on distance of 14 mm from top of the anode (Fig. 1).

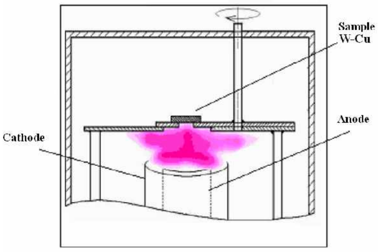

Fig.1. Scheme of the experiment

As an example in the Fig. 2 the view of assembly W-Cu in a place of the action of a plasma stream (tungsten is covered by Cu plate, the irradiation by 40 pulses of deuterium plasma was made).

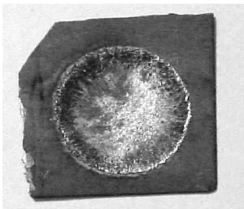

Fig. 2. The view of a surface of a copper foil placed on the W plate after 40 pulses of plasma; the size of the W plate is 2,5 x 2,5 mm

It is visible, that the zone of damage of a copper plate is non-uniform that could be connected to power structure of plasma pulses. It was revealed, that the Cu foil at a high degree adhesion "was welded" to W. To explain this effect only by temperature factor it is impossible, because, as it was already pointed, that Cu does chemically interact with W neither in solid, nor in liquid states. Obviously, shock, or dynamic implantational alloying of superficial layers of W by atoms of Cu takes place. The energy factor of this process could be the spreading vapors of Cu which are forming due to the heating of Cu foil on the surface up to 2500°C under the action of a plasma pulse (calculation was carried out by Dr. S.A. Maslyaev, Institute Metallurgy and Material Science of RAS). Temperature of boiling of Cu is 2573°C. In the case of positive voltage on the anode the generation deuteron beam could take place and the transfer of energy to atoms of Cu can also occur due to elastic collisions with accelerated deuterons [8].

In Fig. 3 the cross section of a sample W-Cu after 40 pulses of plasma is presented. The place of the analysis of structure executed with the help scanning microscope LEO-430 with supplied X-ray spectroscopic module is marked by a cross. Spectrogram of the analysis of structure in the marked point is given in a Fig. 4.

From the carried out analysis follows, that on distance 2 microns from a surface of W the concentration of Cu reaches 9,7 at. %. With the increase of distance from a surface the concentration of Cu at the distance of 5 microns (Fig. 5) is reduced up to 2 at. %. Approximately the same concentration of copper is observed in any point of the analysis in the depth of the sample.

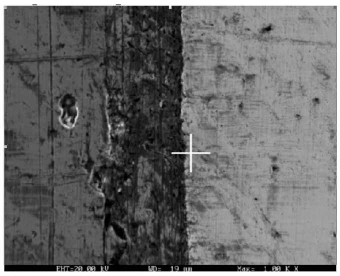

Fig.3. Metallographic section of a sample Cu -W after an irradiation by 40 pulses of plasma. The place of the local analysis of structure of W on the distance 2 microns from a surface is marked

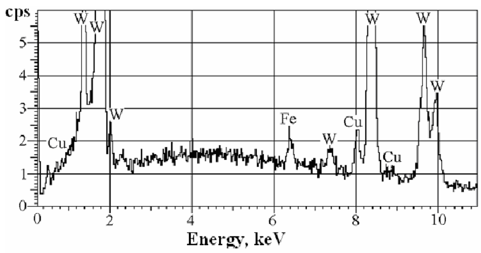

Fig. 4. The x-ray spectrum in the marked point in the Fig. 3

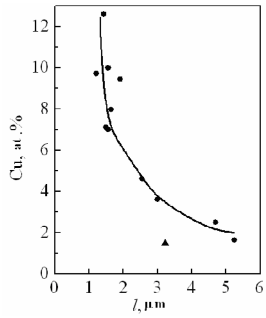

Fig. 5. Distribution of concentrationCu on the thickness of W after an irradiation of assembly W-Cu by pulse plasma

If a surface of tungsten was etched by a solution of H_2NO_3 in pure spirit, the spherical congestions of copper is displayed. The size of these congestions changes from shares of micron up to 1 μ (Fig. 6). These copper congestions are arbitrarily scattered on distance up to 24 μ from a W surface. It is possible to explain the creation of these congestions by the coagulation of atoms of Cu in crystallographic porous, the occurrence of which can be connected to the creation of thermo nonequilibrium vacancies at the front of passing shock waves [9] due to their dissipation on crystallographic imperfections. Thus concentration of formed vacancies, as was shown in [10], can essentially exceed the equilibrium value that provides a high degree of their coagulation even at the room temperature.

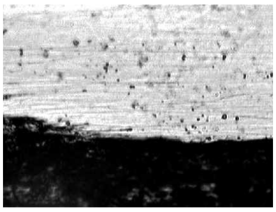

Fig. 6. Distribution of spherical congestions of Cu on the cross-section of a sample Cu-W

The found out non-uniformity of distribution on depth of the introduced atoms of Cu (5-24 microns) is possible to connect both with structural imperfections of W, and with the non-uniform pulse influence of plasma on a surface of copper (see Fig. 2). Besides, the arising due to the high power pulse influence shock waves at their propagation in volume of W can to promote the non diffusion penetration of the atoms of Cu on the depths essentially exceeding the depth of implantation [5, 11].

In the Fig. 7 the sample of tungsten with welded to it copper strips with the use of pulse plasma is presented. Due to the creation of a superficial pseudo-alloy the copper plates are strongly fastened to tungsten.

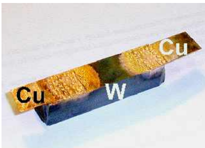

Fig. 7. The sample of W with copper strips welded to it with the use of plasma pulse

CONCLUSIONS

1. A possibility of the use of the concentrated pulse plasma streams of high-power energy to produce the shock alloying of metals by elements which can not compound with them is shown for the first time

2. The nature of penetration of chemically neutral atoms in a material of a target is connected to two processes: the energy transfer to atoms from the concentrated pulse plasma streams and forming and distribution of shock waves in a material of a target.

ACKNOWLEDGEMENTS

The work was supported by the RFBR, project # 05-08-50052, by the grant of President of RF НШ-5489.2006.2 and State contract № 02.445.11.7306

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УДАРНОЕ ЛЕГИРОВАНИЕ МЕТАЛЛОВ КУМУЛЯТИВНЫМИ ПЛАЗМЕННЫМИ ПОТОКАМИ

Л.И. Иванов, А.И. Дедюрин, И.В. Боровицкая, О.Н. Крохин, В.Я. Никулин, Е.Н. Перегудова, С.Н. Полухин, А.А. Тихомиров, Ю.С. Авраамов, А.Д. Шляпин,

Впервые показана возможность ударного легирования металлов элементами, химически не взаимодействующими с ними ни в твердом, ни в жидком состояниях, с помощью концентрированных импульсных потоков плазмы большой мощности, создаваемых в установках типа плазменный фокус. В качестве примера была выбрана система вольфрам-медь. Эксперименты были проведены на установке "Тюльпан" (ФИАН).

УДАРНЕ ЛЕГУВАННЯ МЕТАЛІВ КУМУЛЯТИВНИМИ ПЛАЗМОВИМИ ПОТОКАМИ

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