# Surface Modification by Pulsed Ion Beam

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**Abstract – In the paper the role of current and voltage pulsation in the implanter ion beam with constant supplying voltage and their influence on the obtained material surface properties are discussed. It is shown that for the effective increase of cutting tool durability it is enough to have pulses with the duration of 4…6 ms and frequency up to 100 Hz in the ion beam at the background of constant supplying voltage. The results of instrumental material implantation are presented.**

## 1. Introduction

In the ion implantation setups of instrument steels and alloys with the ion supply system based on constant voltage the ion beam instability representing pulsations appear at the exploitation. Two types of pulsations can be pointed out: at the initial time and in the set mode of surface implantation.

The appearance of pulsations at the initial time is connected to desorption of treated surface gases. The pulsations appeared in the set mode of implantation are caused by the presence of carbon-containing admixtures in the volume of implanted materials and vacuum medium the presence of which is conditioned by the working substance of pumping elements [1].

The overwhelming majority of industrial type implanters have oil system of pumping. Under the action of ion beam the carbon-containing admixtures absorbing at the item surface form films with dielectric properties which cause pulsations in ion beam of randomicity appearing in the form of breakdowns. Moreover, the presence of dielectric layer leads to the decrease of ion beam energy, in the results of which the alloying depth and modification layer decrease while the ion treatment time required for surface hardening increases.

We found out [2] that in order to increase the effectiveness of ion ray hardening of instrumental material surface in the setups of ion implantation with ion source of continuous action it is necessary to use ion current with current and voltage pulsation which can be formed by special oscillatory circuits placed in the ion power supply circuits.

During work the studies of current and voltage pulsation in ion beam of gas-metal source of ions of continuous action based on penning discharge have been performed [3].

## 2. Experimental setup

The experiments have been performed at the ion implantation setup ION-700 which is supplied by the source of gas-metal ions of continuous action [4]. The operation principle of ion source consists in the following. Inside the coaxial source of gas ions of Penning type the target is set. The target is the emitter of metal ions. The accelerating voltage of ions of negative polarity is supplied to the details.

When the gas discharge is initiated in the source the target is sputtered, ions of metals and gases are extracted from plasma of the sputtered target material and are accelerated to the details in the electric field of desk-target. The following modes were used: target materials are Ti, TiB, Al, AlB, working gases are nitrogen, argon, krypton, accelerating voltage of ions is up to 30 kV, ion beam current is up to 25 mA, discharge voltage is up to 1 kV, discharge current is up to 1.5 A, target voltage is up to 2.5 kV and target current is up to 100 mA. The influence of current and voltage pulsation has been studied in the ion beam of gas metal source of ions while implanting instrumental materials of alloy and metal ceramics types.

The mass spectrometry of secondary ions, wear-resistant cutting tests, current and voltage measurements by oscillograph Tektronix TDS-3052 have been used in studies.

## 3. Results and discussion

For the formation of regular pulsations in the ion implantation setup the oscillatory circuits RC-L were placed in the supply circuits of discharge and accelerating voltage. The circuit parameters were chosen by calculations, the optimization of nominal values of elements was done experimentally. Figure 1 shows the current and voltage oscillogram measured by oscillograph Tektronix TDS-3052 in the power circuits of accelerating voltage at the output of oscillatory circuit. The measurement was done by voltage divider with the point factor of 1000, and shunt with 51 Ω resistance.

From the presented oscillogram it follows that when there is oscillatory circuit the regular short pulses of reverse polarity with 4–6 ms duration are formed in the ion beam. At that the 2.5-time-over-load of source takes place (discharge current is 250 mA, charge current is 100 mA). The duration of oscillatory

period is 10 ms what corresponds to the operation of ion source frequency which is 100 Hz.

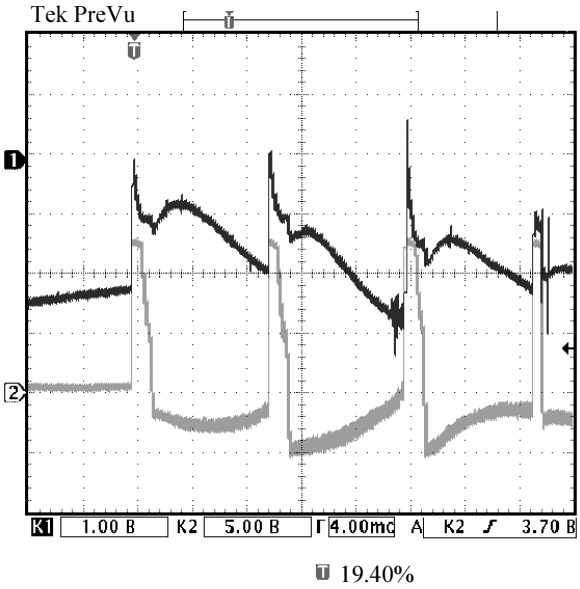


Fig. 1. The current and voltage oscillogram in the ion acceleration circuit. Channel 1 is discharge current of K75-74-40-kV-22 nF capacitor (100 mA/point). Channel 2 is voltage (10 kV/point)

What are the advantages given by the application of regular pulsations formed at the background of constant accelerating voltage?

As it was noted before, the reason of unstable operation of ion source in the setups with oil pumping is the presence of carbon-containing admixtures which absorb at the item surface and coagulate under the action of ion beam forming dielectric coatings with constantly changing resistance. The time of dielectric layer existence is comparable to the calculation time of implantation. In the implanters which have the system of integral dose alteration the implantation time can become 2…3 times longer as the result. In the devices, the dose accumulation of which is determined by time the risk of bad quality surface hardening increases. The process of film destruction under ion beam action is complicated and not stable in time. The presence of regular pulses of reverse polarity in ion beam helps the dielectric layer destruction. Moreover, the oscillatory circuits help the formation of pulsed increase of accelerating voltage of ions. This positive phenomenon leads to the increase of depth of alloying and surface layer modification. Figure 2 shows the results of surface alloying of T15K6 alloy by Al ions in the conditions of ion source operation with constant accelerating voltage without and with pulsations. It is obvious that when the pulsed mode of ion source is used the alloying depth increases. This can be seen by the increase of concentration profile curve width for comparable values of accelerating voltage. The presence of hump at the curve of concentration profile for pulsed mode is related to the increase of accelerating voltage increase in pulse.

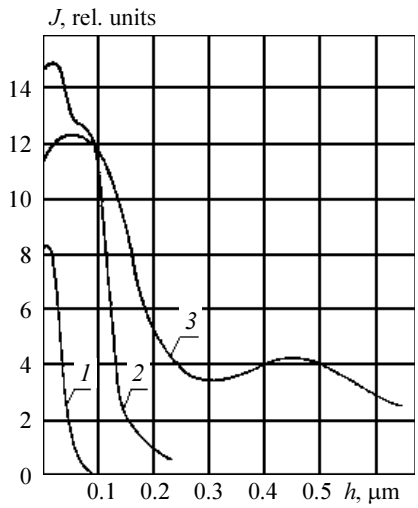


Fig. 2. The distribution of implanted aluminium at the surface of T15K6 alloy. The working gas is nitrogen. The analysis method is mass spectroscopy of secondary ions. The implantation mode is: *1* – $U = 25$ kV, $\Phi = 10^{17}$ ion/cm$^2$, $j = 20$ μA/cm$^2$; *2* – $U = 50$ kV, $\Phi = 5 \cdot 10^{17}$ ion/cm$^2$, $j = 20$ μA/cm$^2$; *3* – pulsed mode of implantation at $U_{average} = 22$ kV, $\Phi = 5 \cdot 10^{17}$ ion/cm$^2$, $j = 100$ μA/cm$^2$

The pulsed mode of ion beam allows making the hardening of ceramic instrumental materials. Figures 3 and 4 show the results of durability tests of instrumental ceramics based on aluminium oxide implanted by $TiB_2N$ ions.

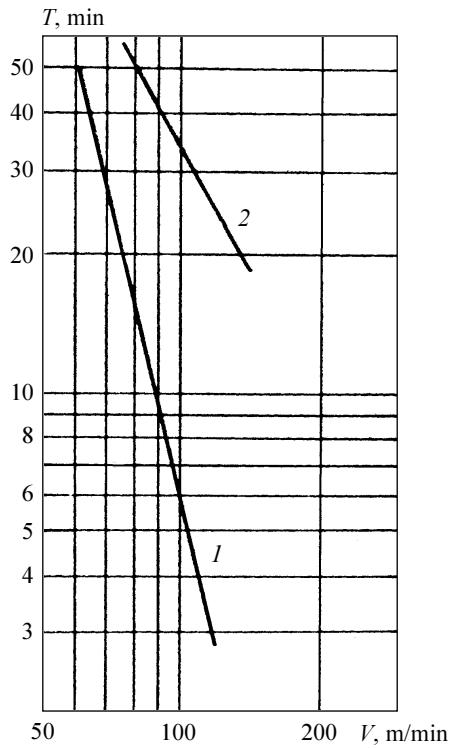


Fig. 3. The dependence instrumental ceramic durability based on $A_2O_3$ on cutting speed *V* while turning KhVG hardened steel $HR_c$ 61–63 units: *1* – initial tool; *2* – implanttation by $TiB_2N$ ions

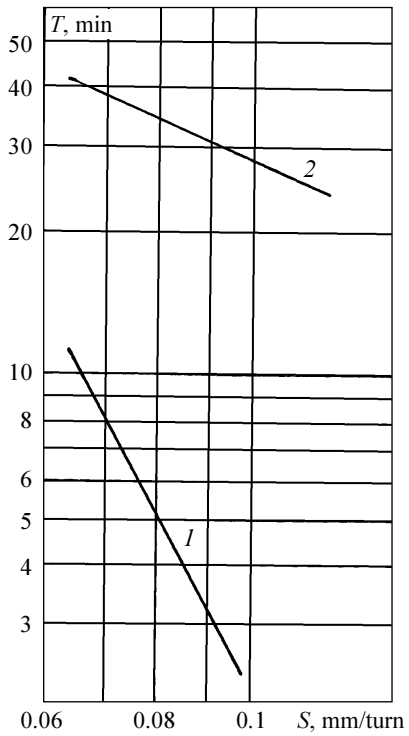


Fig. 4. The dependence of instrumental ceramic durability based on $A_2O_3$ on cutting supply S while turning XBΓ hardened steel $HR_c$ 61–63 units: *1* – initial tool; *2* – implantation by $TiB_2N$ ions

The instrumental ceramics have the properties of dielectric. The treatment of its surface by continuous ion beams does not seem possible due to the accumulation of discharge at the surface which pushes the ions away. The ion ray treatment of ceramic instrument in the pulsed mode of ion beam allowed making speed and cutting supply 1.5 times higher at turning of KhVG hardening steel with the hardness of $HR_c$ 61–63 units and making the time of its operation 6–7 times higher.

## 4. Conclusion

The test results show that:

1. The regular pulsations of current and voltage in the ion beam allow increasing the ion implantation effectiveness of instrumental materials especially when hardening instrumental ceramics;
2. It is enough to organize the pulses with 4–6 ms duration and 100-Hz frequency in order to reach the effective increase of cutting tool durability;
3. The presence of pulses with the amplitude higher than the accelerating voltage in the ion beam allows decreasing the energy consumptions for tool hardening;
4. The application of ion implanters with pulsations in ion beam allows decreasing the requirements to the purity of vacuum and applied pumping substances.

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