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GENERATION OF HIGH INTENSIVE AND HIGH POWER METAL IONS BY VACUUM ARC *TAMEK* SOURCES

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Abstract

This paper presents a review of vacuum arc facilities to be as injectors for metal ion accelerators. A vacuum arc in different modes: 1). Arc current I_{arc}=2-50 A, pulse duration t_p=10 μs to 20 ms; 2). I_{arc}=20-100 A, t_p=50-1000 μs; 3). I_{arc}=100-2000 A, t_p=100-2000 μs; 4). I_{arc}=10-100 kA, t_p=1-10 μs were investigated as metal ion injectors. The metal flows generated by cathode spots are expanded for diameters of 10-50 cm, and then, or deposited on the grounded target, or post accelerated between grids at U_{accel}=10-120 kV. On the basis of such injectors the series of TAMEK sources were investigated with metal ion current from I_i> 0.01 A, pulse duration up to 20 ms, up to I_i<5 kA, t_p=1-5 μs.

Introduction

Ion beam modification of metals, composite materials, ceramics, glass, polymers is used to improve surface properties such as wear, corrosion and friction resistance, hardness, electrical conductivity, wettability, etc., [1]. In 1984 the authors of Refs.[2-8] started to develop vacuum arc metal ion sources for surface modification technologies. The development was made by designing Technological Accelerator of Metal Ion and Electron Kit (TAMEK sources) which were capable of generating both high-energy metal ion beams and low-energy plasma from the same cathode material, thus providing high-dose (intensive) metal ion implantation (HDI), ion deposition, ion mixing and ion beam assisted deposition (IBAD).

1. Versatile TAMEK source

TAMEK is a vapour vacuum arc source of multiply charged ions (from Me^{+2} up to Ta^{+6}, W^{+6}) emitted from any hard cold electroconductive cathodes (fig. 1). The alternation of HDI and low-energy ion deposition (fig. 2a) was proposed [5]. In the pulsed mode (f<100 Hz) both ion implantation at E_i<200 keV, U_{accel}<100 kV, the dose accumulation rate on the grounded target $dD_i/dt<10^{16}$ ion/cm^2/min, and deposition of the same ions at E_i<100 eV, coating growth rate dH/dt=50-200 nm/min, are implemented during each pulse.

As the accelerating voltage polarity is reversed, the source generates an electron beam with E_e<100 keV, I_e<5 A.

Modular design of the TAMEK source (fig.3) permits us to install it on a vacuum chamber. It is easier to adapt the TAMEK sources for generation of ion beams with the spot size of 2000 cm^2. For this purpose it is only necessary to replace the conical anode and the extracting grids by new ones of corresponding diameter, as the plasma and ion flows from the vacuum arc cathode spots are expanded forward at angles of 60-120 degrees for different cathode materials. We have lengthened the electrodes to obtain the diameter of 50 cm.

The TAMEK sources can efficiently generate high-melting metal (e.g., W, Ta) ions which are hardly available with other types of sources. To obtain mixed ion beams we used cathodes made from alloys and composites such as TiB_2, TiC, TiSiC, TiMoSi, SiC, MoS, CuMoSi, CuSiC, AlBW, NiCrAlY.

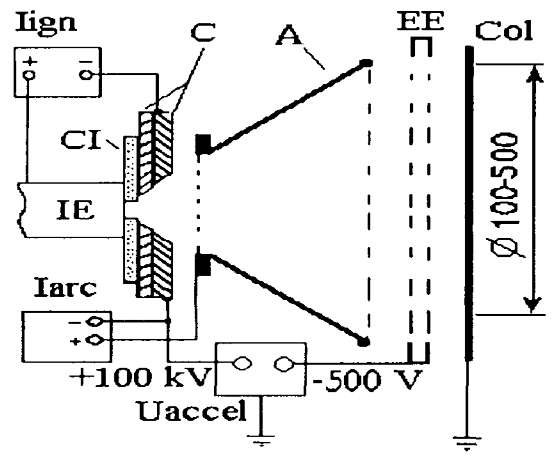


Fig. 1. Scheme of the TAMEK source. A-anode, C-replaceable disk cathodes, IE-igniting electrode, CI- ceramic insulator, EE-grid extracting electrode, Col-grounded collector.

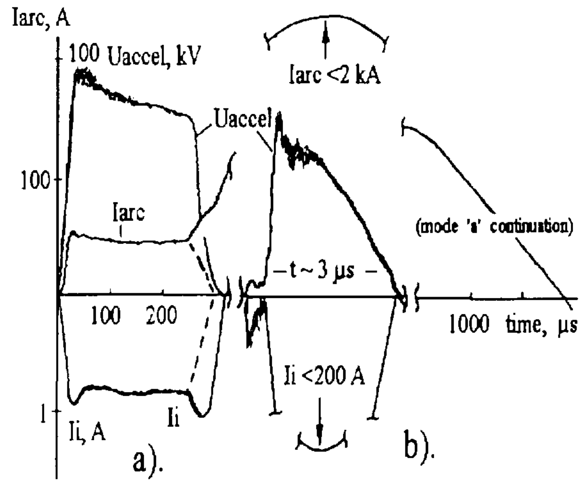


Fig. 2. Signals of TAMEK source operational modes. a), IBAD mode with HDI; b), IBAD mode with HPIB. U_{accel}, accelerating voltage; I_{arc}, vacuum arc discharge current; I_i, ion current. Dashed lines indicate I_i and I_{arc} in the HDI mode without ion deposition.

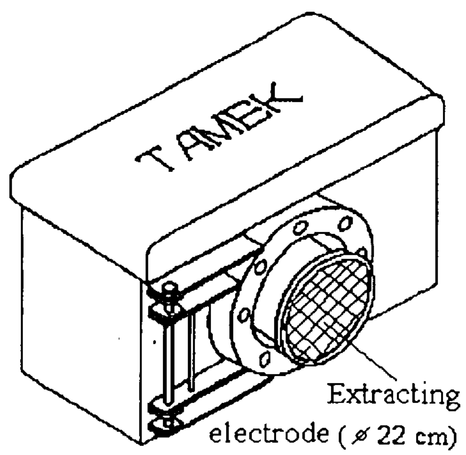


Fig. 3. TAMEK source picture. High-voltage power supplies and an ion gun are located in the space of 70x40x25 cm^3.

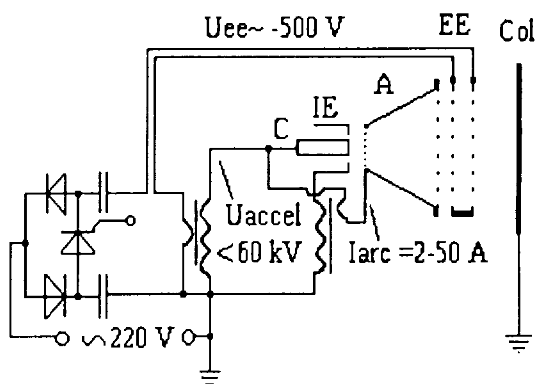


Fig. 4. Scheme of the source with low current vacuum arc.

2. Low current millisecond duration vacuum arc source

Special scheme (fig. 4) was proposed [6] for realization of both an extra low current and long pulse duration vacuum arcs. This scheme automatically reignites the arc for all accelerating voltage. A low current vacuum arc can be produced with the single emitting center in the cathode spot, e.g., a sequence (up to 20 ms) of single short pulses was generated at a current I_{arc}=2-4 A for copper cathode, and I_{arc}=8-10 A for tungsten cathode. At higher arc current the source operates more stable and generates low intensity metal ion beams of time duration determined only by the power supply transformers. Such low current vacuum arc mode generates more highly stripped metal ions due to more less de-ionization of metal ions in the low density near surface cathode plasma.

3. TAMEK-M sources of microsecond duration high power metal ion beams

At a high current vacuum arc it is possible to use only one discharge gap without triggering for microsecond duration metal HPIB generation [7]. The direct capacitance discharge (fig. 5) is used for metal plasma generation after ignition of Marx generator.

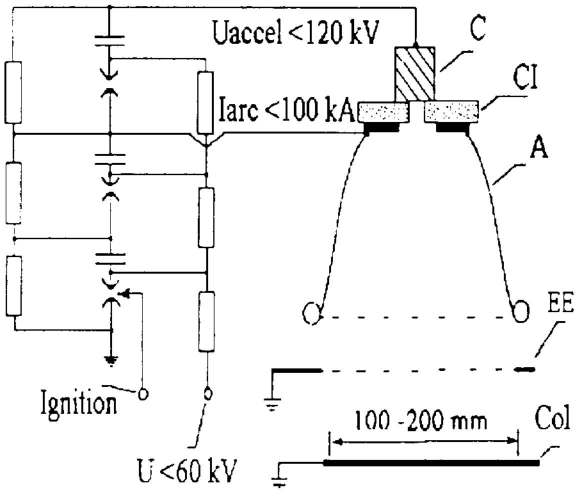


Fig. 5. Scheme of TAMEK-M source.

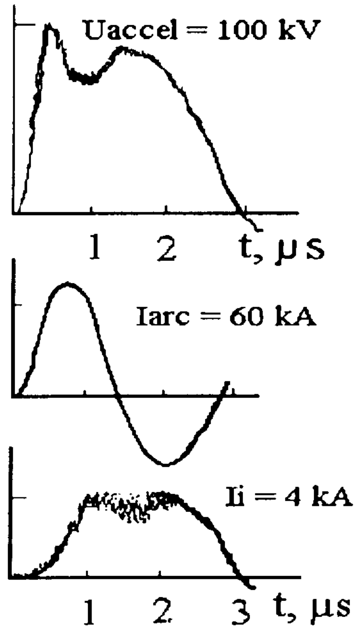


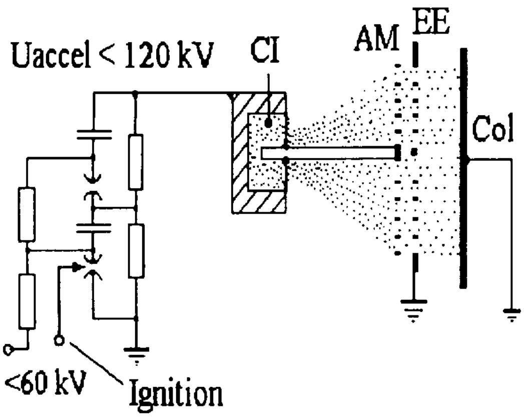
Fig. 6. Typical pulses for TAMEK-M source (fig. 5).

Source on fig. 7 uses Archimedes spiral type path of the anode -AM for creation of a magnetic field for electron insulating. At the beginning of a pulse the electrode -AM has a floating potential, that lead to the surface flashover on the insulator -CI and cathode sports formation on the road part of the anode. Simultaneously, the magnetic field from this electrode increases the anode plasma ionization. At I_{arc}<100 kA (fig. 6) such sources generate metal ion current I_i<5 kA, t_p=0.5-10 μs. For a shorter pulse duration it is difficult to achieve a low inductance of a vacuum arc discharge circuit, to take also into account the rather big capacitance which is necessary to generate a high arc current. Upper limit for pulse duration is restricted by necessity to adjust the accelerating gap with Child-Langmuir limit for the ion current density and closing the accelerating gap by an explosive cathode plasma. Due to high speed of vacuum arc anode plasma motion and its erosion during a pulse for vacuum arc ion sources it is possible to use accelerating gaps up to 10 cm. Parameters received: U_{accel}<120 kV, I_i<5 kA, t_p=1-5 μs are enough for successful metal surface modification with the surface energy input of dW=0.5-5 J/cm^2 [4,9,10,13].

In the reversed mode such sources generate electron beams with current of I_e<50 kA.

4. Plasma immersion metal ion implantation

A combination of conventional metal vacuum arc PVD method and plasma immersion metal ion implantation (PIII) are proposed [8]. Fig. 8 presents the scheme of the combination of PVD and PIII. Unlike the other authors [11], we have come to the conclusion that PVD and surface modification by HPIB is a promising combination. We make use of metal plasma density of D_p=10^{12}-10^{13} cm^{-3} generated by a vacuum arc at I_{arc}=100-2000 A, and a low induction power source with U_{accel}<60 kV which is periodically (one pulse in 0.5-3 min) switched on between the target and the plasma source. HPIB generation with I_i<200 A, t=1-3 μs takes place through alternation of HPIB and PVD, and vice versa without a time break (fig. 2b).



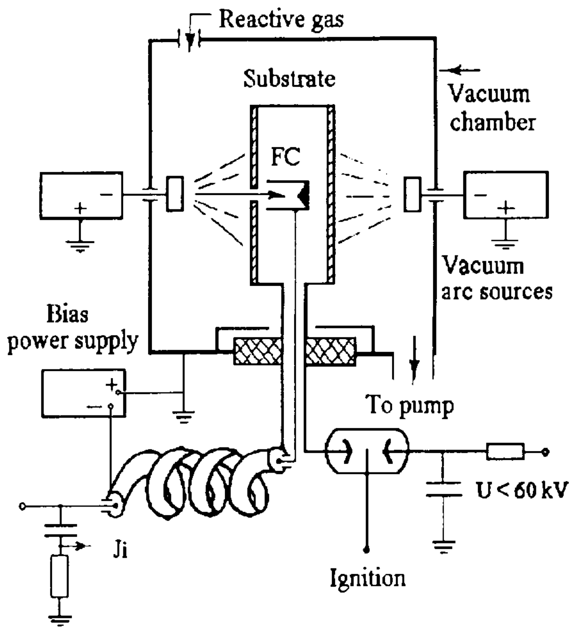


Fig. 7. Scheme of the HPIB source with self-generation of an anode plasma and insulated magnetic field.

Fig. 8. Scheme of the source for combination of PVD and metal PIII by a high power metal ion beam.

Conclusions

This short review has demonstrated that using unique properties of vacuum arc to generate metal ions it is possible to construct metal ion accelerators with broad range of parameters. Improved coating adhesion with easy sample preparation and modular design of the TAMEK sources make they convenient for industry applications. Vacuum units can thus become versatile and capable to implement surface modifications by HDI, IBAD, HPIB and metal PIII, or electron irradiation.

TAMEK sources can be used successfully in conventional application fields of ion implantation and physical vapour deposition, e.g., in textile, paper, plastics, food, aeronautics and space industries, medical sector, etc. As a rule, service time of treated parts is increased by 2-15 times, but it is much longer for parts whose service time depends on corrosion and wear resistance, such as notching dies, disk milling cutters, trimming knives, blades of aviamotors, valves from a cryogenic and other compressors, relay and other contacts. The most attractive examples here are tools used for shaping, cutting, and piercing of plastics, papers, synthetic fibers, soft tissues and similar materials [1,4,9,10,12,13]. So, it seems that vacuum arc sources such as TAMEK can occupy an important position on the technological market of devices for surface modifications by ion, plasma and electron beams.

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