SOURCE OF INTENSIVE OXYGEN PLASMA FLOWS OF LOW ENERGY FOR TECHNOLOGICAL APPLICATIONS

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Abstract

The external magnetic field magnetoplasma dynamic accelerator is adopted to produce low energy oxygen plasma jet by Ar-flow-hollow cathode using. Double arc contraction by ferromagnetic intermediate electrode with pumping reduces plasma jet contamination of electrode material up to $4 \times 10^{-6}$. The source produces the oxygen plasma jet with ion current density $5 \text{ mA/cm}^2$ in the energy range 20-60 eV. Its maintenance-free lifetime is some 100h.

Introduction

At present the interest has grown in creation of the intensive oxygen plasma or ion flows with the energy lower 100 eV [1]. It is caused by the requirements to make thin films with perfect structure and also the simulation of action of elemental oxygen on spacecraft materials.

In the film fabrication technology the film properties such as crystalline structure, film density, electrical resistivity and refractive index can be controlled by bombarding growing film with inert or reactive gas ions. The interactions between ions and thin film surfaces are strongly dependent on the incident kinetic energy of the ions. Considering the energy dependences of damage creation, the sticking probability, the surface cleaning effect, and the enhanced adatom migration, the optimum kinetic energy range for deposition and epitaxial growth of the films is between a few eV and 100 eV [2].

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Spacecraft in low earth orbit (200-500Km height) are exposed to a rarefied atmosphere which is, to a large extent, composed of atomic oxygen (ATOX). It can interact with the spacecraft in a number of ways and in particular can cause undesirable erosion or degradation of spacecraft materials. Thus ground-based test facilities are needed to investigate the principal mechanisms of erosion appropriate choice of materials used in spacecraft construction[3].

The problem of material erosion in oxidative plasma is existed in fusion technology too. Under plasma-wall interaction the wall impurity oxygen ions are produced intra-cavitarily and sputter of wall material chemically. To predicate materials behavior the simulative tests are requisite [1,4].

All technology branches mentioned are in needed of high-intensivity oxygen plasma flow source with ion translation energy lower 100eV. Another common requiments are 1) ion current density more of 1ma/cm², 2) long durability sufficient to material tests durations(100h). 3) minimal beam contaminants.

Plasma or ion sources usually used in the practice are suitable for it in little degree. Kaufman ion source of low energy with one-grid ion optics (IO) possesses a small lifetime (a few hours) because of the rapid IO destruction in the oxygen. In addition since most of the conventional high-current ion sources utilize metallic hot cathodes and are operated at a hight-discharge current and considerably low gas pressure, the lifetime of the metallic hot cathodes is rather short and it usually limits the lifetime of the ion source.

In opposite a closed electron drift plasma accelerator is supplied with Ar-gas-flow hollow cathode. That results in long life operation in oxygen plasma [5], but the oxygen plasma flow energy
is found to be too high (100eV and more). Low translation energy ions can be produced by magnetoplasma dynamic accelerator (MPDA) intended for a ground based ATOX simulation [6]. The accelerator is self-induced magnetic field MPD thruster type. The oxygen plasma jet energy is expected to be in the range 3-15eV. However when oxygen gas operating the MPDA electrodes effects limit performance duration (some minutes) and result in jet contaminations.

Oxygen plasma source design and performance

This paper concerns the oxygen plasma source advanced. Contrary to the thruster above mentioned the source is based on external magnetic field MPDA configuration [7].

Inside the MPDA the regimes of acceleration with plasma air flows with velocity of 5-20 km/s are known [7]. In the accelerator of this type you can create conditions when the electrons move along the lines of magnetic forces and their directions to a considerable extent coincide with the lines of plasma flows. The electric field and electron temperature are not great and it is possible to make flows with energy not higher than ionization one [8].

When developed the main difficult problems were to design a thermoelectron arc cathode with a long lifetime in the oxidative arc and to purify oxygen plasma jet of contaminants.

The development of traditional MPDA scheme with the filament working directly in the oxidative are permitted the source durability to be no more than a few hours due to cathode erosion. Zirconium or hafnium cathodes known as thermo chemical have a long durability in atmospheric oxygen arc owing to protective oxide layer creation and maintenance in oxidative plasma.

The application of the thermochemical Hf emitter oxygen failed to increase the source lifetime because of the destruction of the protective emissive layer by ion bombardment in low pressure arc of
The long lifetime of the source (up to 100h) was ensured when the hollow inert gas cathode was employed. The diaphragmed LaB6 emitter cathode developed for the "FOBOS" program served as prototype [10]. The finished cathode assembly of the source is made in the form of a diaphragmed Mo pipe which is half filled with LaB6 grains. The pipe is surrounded with the spiral start-up electric heater. The cathode assembly is arranged inside the cylindrical thermoscreen. The inert gas fills the screen hollow flowing through the pipe, and in such a way it protects not only LaB6 emitter but also the exterior pipe and heater surfaces inside the screen. In this way the source life time in between LaB6 grains substitutions is found to be near 100 hours in dependence on cathode flow-Ar-gas purity.

The plasma jet contamination problem being minor for thruster is important for technology source. The cathode erosion products and inert gas are the impurities of the oxygen plasma jet of the MPDA. The electrode material atoms are transported by plasma jet to an irradiated surface, are deposited and disturbed its behaviors. The inert gas is pumped poorly by some type of vacuum pumps as sputter-ion ones.

To reduce the impurities yield to the plasma stream we employed magnetic and geometric arc contraction by ferromagnetic intermediate electrode (IE) as in the duoplasmatron [11]. The contraction creates potential barriers limiting cathode plasma ions (cum contaminants) moving towards the anode plasma in which the jet is formed. For the more complete decrease of the neutral impurities yield to the anode plasma, the IE hollow is pumped complementary. The pumping reduces pressure in the IE and maintains in the IE channel gas flow which is contrary the electrons[12]. The relationship between intracavity IE pressure and plasma jet ion currents
ratio of Xe-impurity to oxygen is shown in fig. 1.

The schematic diagram of the source is shown in figure 2. The anode 1, IE 2, cathode 3 are arranged inside the solenoid 4. The distribution of magnetic induction in the anode and downstream corresponds to its distribution in the MPDA, and in front of the IE and at its channel it is analogous to the distribution in the duoplasmatron. The plasmaforming gas oxygen is fed in the anode and the inert gas argon or xenon runs through the cathode by pipelines 5 and 6. The IE cavity is pumped through vacuum line 7.

The source performances were investigated in the vacuum facilities with differential diffusion pumping 2 and 1 m³/s and plasma diagnostics by two-probe technique, a three-grid energy analyser and a monopolar mass-spectrometer [13]. The oxygen plasma flow measured at a distance of 0.2 m from the anode had ion current density up to 5 mA/cm² with 3 cm diameter on level 0.7 max. Varying the magnetic field, gas and electric supply consumption, you can control the ion current density. Figure 3 shows the ion current density as a function of discharge current. The average ion energy is in the range of 20-60 eV, and the fluxes ratio O⁺/O₂⁺ is at the interval of 0.3-3. The indicated performances are obtained with oxygen gas flow equal to 0.5 cm³/s, argon or xenon flow equal to 0.1 cm³/s,
6-12 A arc current. 60-100 V arc voltage.

The impurity ions of construction materials and inert cathode gas (Xe) were not observed during the mass spectrometry of plasma flow with 5×10⁻⁴ sensitivity limit. Construction materials contaminates were measured by deposition probe technique with Rutherford Back Scattering method. The Fe atoms were found to be some 4 per million oxygen ions in plasma jet [14].

The described source was used in the investigations of degradation of spacecraft and thermonuclear reactor materials in oxygen plasma flows [15,16].

References


