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MANUFACTURE OF IONIZERS INTENDED FOR ELECTRIC PROPULSION

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16. Abstract

The paper describes an electric propulsion system which relies on the formation of cesium ions in contact with a porous wall made of a metal with a high work function when the wall is heated to 1500 K. The manufacture of porous walls on the mountings are considered. Erosion of the electrodes by slow ions is examined, and the life times of the ionizers is estimated by means of experimental studies. The purpose of the electric propulsion system is to bring about minor corrections in the orbits of geostationary satellites; the main advantage of this system is that it weighs less than currently used hydrazine systems.

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MANUFACTURE OF IONIZERS INTENDED FOR ELECTRIC PROPULSION

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I - Introduction /1*

Many applications, such as telecommunications, direct television, meteorological surveillance, taking navigational bearings, etc., require the use of geostationary satellites which are in a fixed position with respect to the earth. Disturbing effects exerted on these satellites (for example, solar radiation pressure, lunar attraction, anisotropy in the earth's gravity field, etc.) periodically require the application of a small corrective thrust (1-10 mN) supplied by devices with a substantial service life (5-7 years). In comparison with the the hydrazine propulsion systems currently used, the use of electric propulsion for this task would permit the total weight of a satellite weighing from 400 to 800 kg to be increased more than 10% [1]. The cost of production for the new system would be comparable to that of the hydrazine system. The principle of this type of propulsion consists first of all accelerating heavy ions by means of high-voltage (about 3 kV) electrostatic optics and then in a second step adding to the ions, which have then acquired a speed on the order of 60 km per second, the electrons which were previously removed in order to reestablish the electric neutrality of the system.

Among the various ionization methods used to achieve this, the formation of cesium ions (an element with a low ionization potential, 3.9 eV) in contact with a wall consisting of a metal with a high work function and heated to 1500 K has been studied in detail by ONERA at the request of the CNES. To obtain a contact as close as possible between the two substances, and thus

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* Numbers in the margin indicate pagination in the foreign text.

an increased coefficient of ionization (greater than 99%), the cesium vapor is blown in across a porous wall.

II - Required Characteristics and Manufacture of Porous Walls

The choice of the type of porous wall intended to ionize the cesium vapor is very restricted since the material has to combine a high degree of refractoriness and a high work function. In practice, only tungsten sufficiently combines these two conditions. Moreover, it is not soluble with cesium. However, its function as an ionizer imposes on it other necessary and sometimes contradictory characteristics:

1. Sufficient permeability to gases or vapors to allow a suitable flow of cesium with a moderate temperature /2 for the vaporizor, which assumes a substantial overall porosity and a small thickness.
2. Porosity which is homogeneously distributed in the form of very fine pores (1-3 μ) so that a minimum of cesium atoms escapes from the ionizer.
3. Ability to conform a specific radius of curvature in order to pre-focus the ions.
4. Dimensional and structural stability in a vacuum at 1500 K for thousands of hours.

This last point especially deserves attention because it is obvious that a high porous, finely-grained material possesses considerable free energy which will tend to decrease as a result of recrystallization and contraction. A device to block these unacceptable phenomena must be provided. It has been shown earlier at ONERA that a fine dispersion of thorium oxide in a nickel powder ensures this blockage provided that the particles do not exceed 1000 Å.

An efficient dispersion process based on the wetting of nickel oxalate by a solution of thorium acetylacetonate has been proposed, Fig. 1, [2].

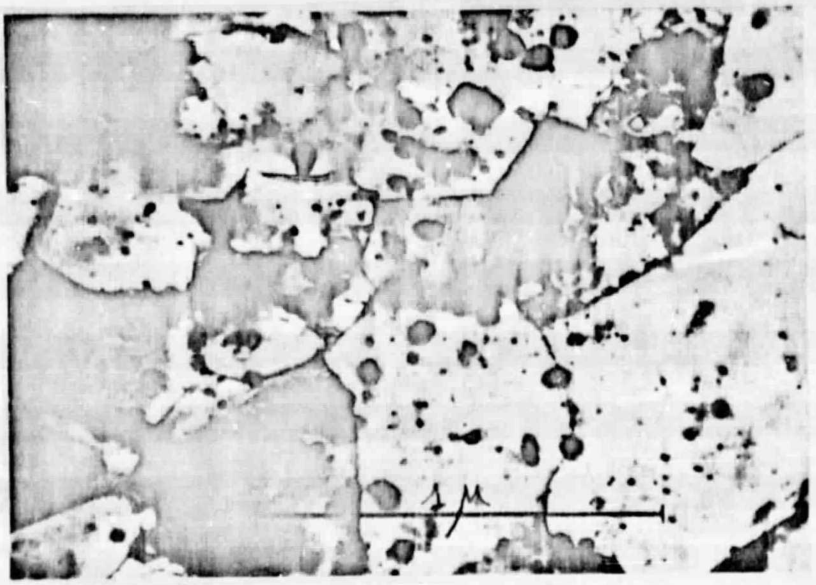

Fig. 1. Dispersion of thorium oxide in a nickel matrix obtained by the thorium acetylacetonate process.

Elsewhere, at about the same time, a process for manufacturing nickel chromium porous membranes was developed [3].

It consists of mixing an organic binding agent, which can be sublimed, with the metallic powder and then making flexible sheets by calendering.

These sheets can then be cut, dried to eliminate the /3 binding agent and fritted. The advantages are appreciable.

The porosity which takes the place of the organic binding agent is very well distributed and, on the whole, it is precisely determined. The thickness can be reduced to 0.2 mm, and then after drying the sheets can be shaped by hot stamping, therefore eliminating any machining and thus any filling of surface pores.

It is the combination of these two techniques which has permitted the manufacure of these porous tungsten walls required for ion propulsion experiments [4]. The different steps in the

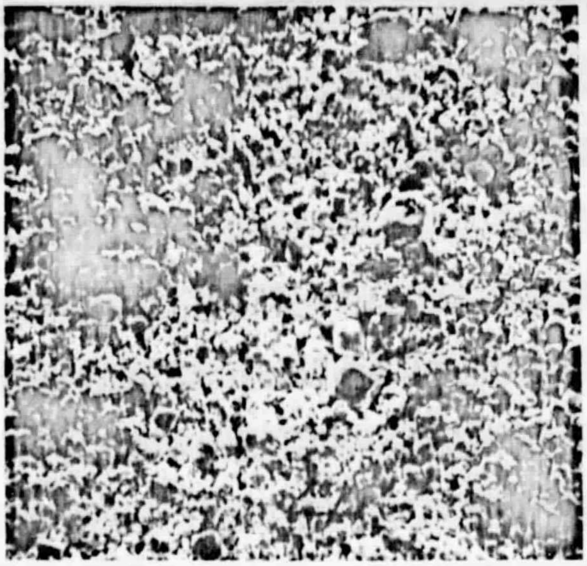

Fig. 2

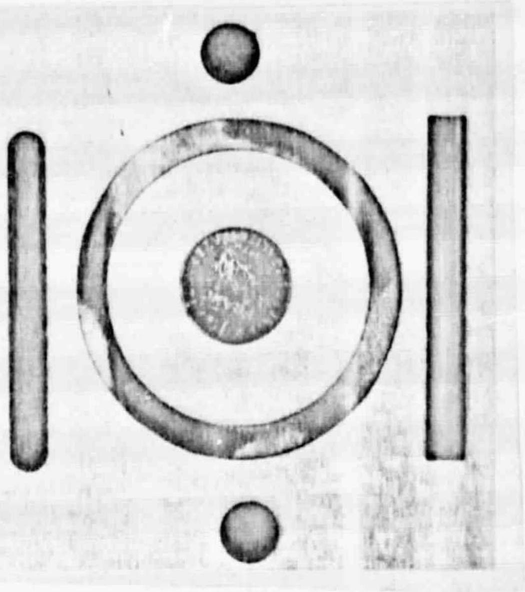

Fig. 3

process are the following: (1) wetting WO_3 with a solution of thorium acetylacetonate; (2) calcination at 800°C; (3) reduction in H_2 at 900°C; (4) mixing the tungsten powder with a solution of methyl polymethacrylate cyclohexanone; (5) calendering the paste to obtain a flexible sheet of suitable thickness (0.6-1.5 mm); (6) cutting to the desired shape; (7) drying; (8) (8) smoothing; (9) stamping; (10) elimination of the binding agent by gradual heating in H_2; (11) fritting in H_2 at 1550°C. Fig. 2 shows the surface state of the material obtained. The number of pores reaches 30 million per square centimeter which guarantees a good ionization yield. Fig. 3 shows a few types of porous walls which have been made.

The spherical caps are provided to equip propulsion systems called "monobuttons" whose thrust is 0.5 mN. The strips are for propulsion systems called "mono-slits" whose thrust is on the order of 1.5 mN. The ring is supposed to be installed on an annular propulsion system whose thrust might attain 5 mN.

III - Design and Fabrication of the Mountings

/4

The mountings must reliably perform several functions: (1) hold the porous wall in place; (2) receive and uniformly distribute the cesium vapor; (3) transmit to the porous wall which radiates in space the thermal flux necessary to maintain the temperature equilibrium around 1500 K. Fig. 4 shows a section of a mounting intended for a monoslit propulsion system. The reason for sloping the partition is to ensure a homogeneous flux of cesium starting from a single input tube. Heating is accomplished by coiled tungsten filaments covered with aluminum oxide inserted into logitudinal cavities.

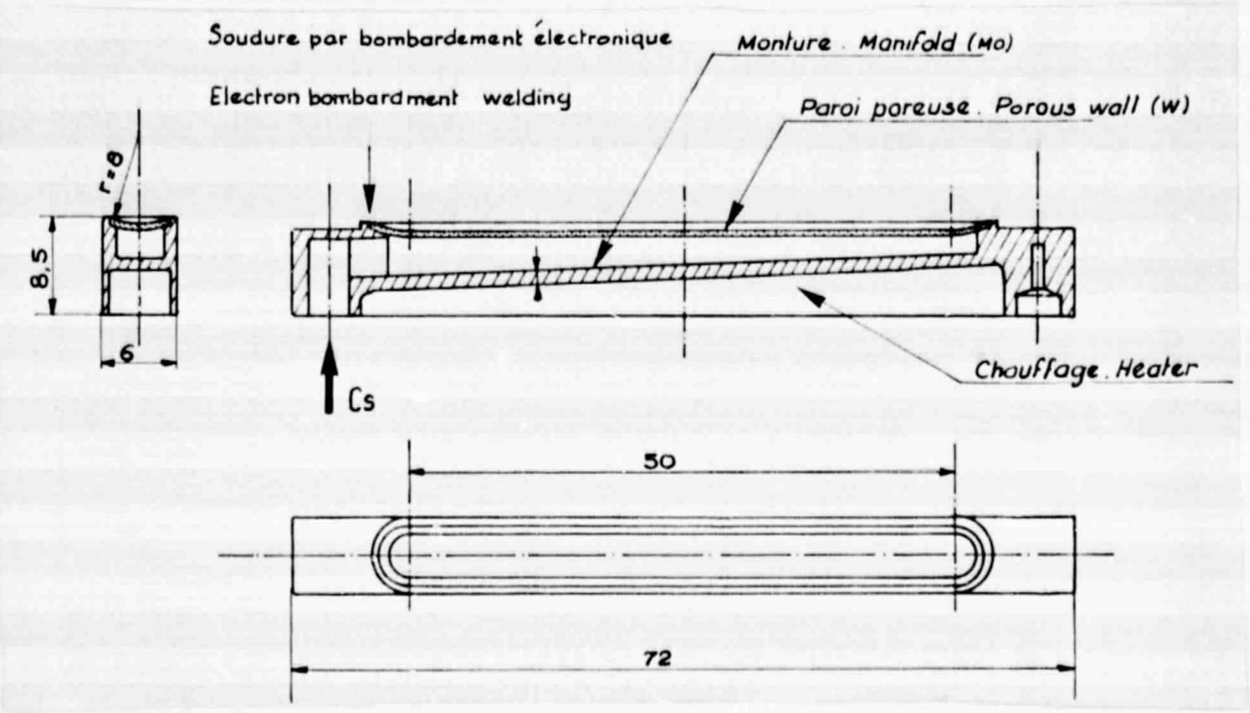

Fig. 4. Initial emitter mounting.

The required properties of the material to be used are that it be highly refractory and have a high level of thermal conductivity. The latter condition excludes tantalum. The choice is limited to molybdenum and tungsten. The first has the advantage that it can be easily worked either with machines or by electroerosion methods, but its expansion coefficient is greater than that of tungsten and thus stresses would be expected to occur between the mounting and the porous wall in the course of thermal cycles. Tungsten avoids this drawback, but it is difficult to work even by electroerosion methods. This is why mountings of this type have been made by pyrolytic decomposition of tungsten hexofluoride on pieces of copper ultimately eliminated by treating with acid [5].

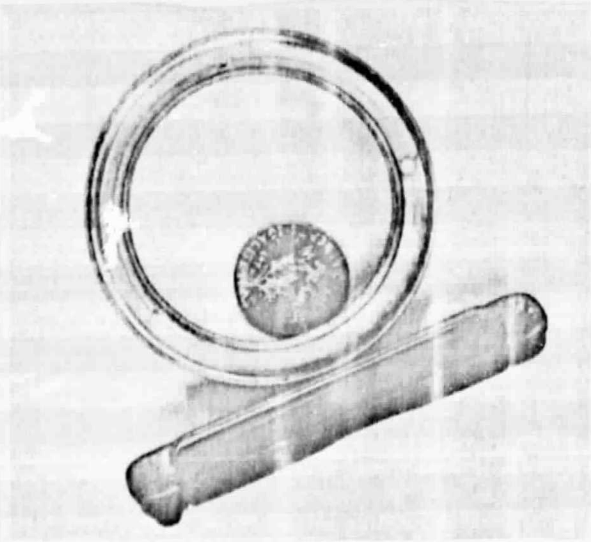

Fig. 5. Mountings made of pyrolytic tungsten.

With this technique it is even possible to imagine mountings of molybdenum-tungsten mixtures. /5

Fig. 5 shows two particular models for monoslit and annular propulsion systems.

IV - Junction of Porous Walls on the Mountings

The porous walls, since they have to remain unfinished at fritting, cannot meet strict dimensional tolerances. Therefore the groove in the mounting intended to hold a wall must be fitted

Fig. 6-a

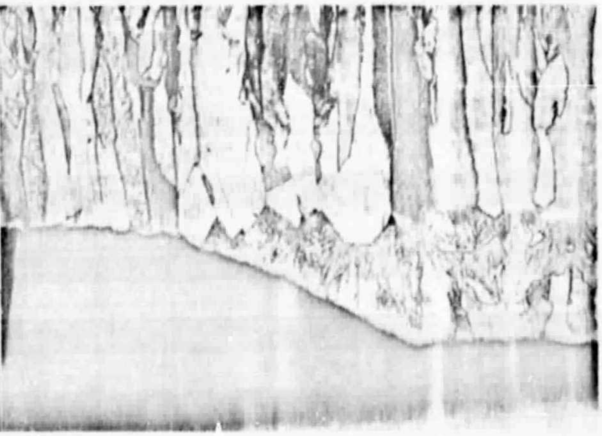

Fig. 6-b

to the wall. Molybdenum, which can be easily machined, does not pose any problems. For tungsten mountings, pyrolytic electro-erosion turns out to be disappointing because of the cracks which it causes (Fig. 6a). By contrast, machining using ultrasonic techniques has proved its efficiency (Fig. 6b).

As for the joint, welding by electron bombardment can reliably be used on small rotating pieces such as monobuttons (Fig. 7) /6

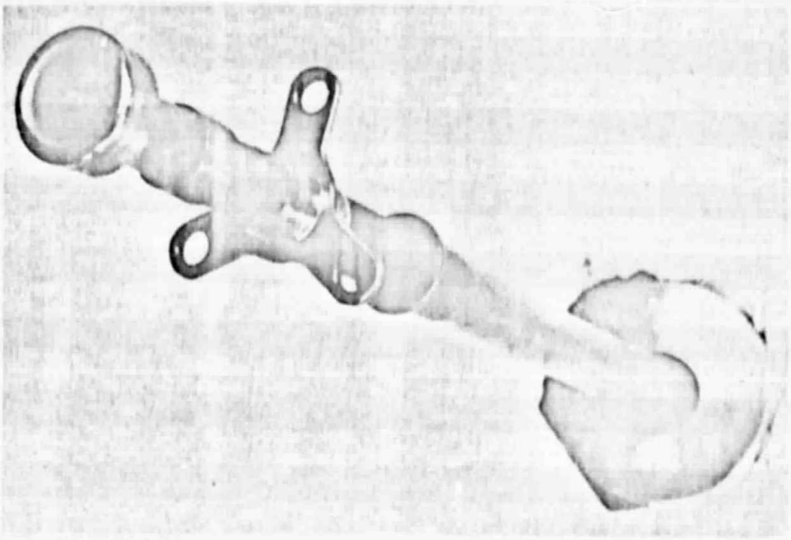

Fig. 7

By contrast, difficulties turn up with monoslit propulsion systems because of the large thermal gradients caused by this welding technique. Substantial wastes have occurred. As for annular propulsion systems, the operation has turned out to be impossible by performing two bands of welding one after the other since the second always causes the porous wall to rupture. This is why recourse was again taken to the pyrolytic deposition of tungsten which, provided that the porous wall is protected by a copper mask, can insure a tight joint with the mounting under isothermic conditions (Figs. 8 and 9).

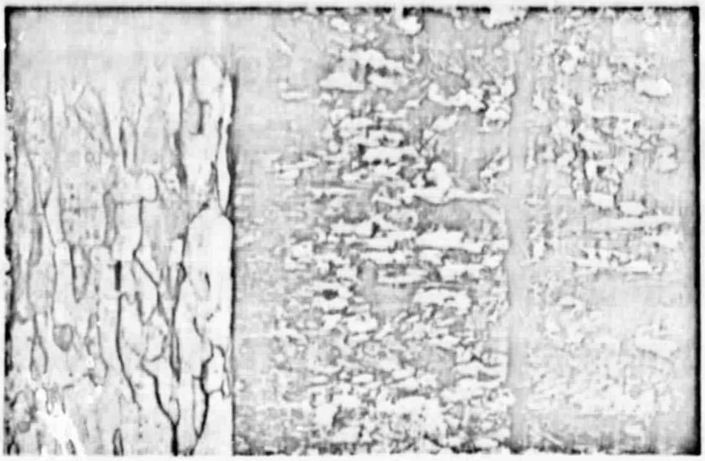

Fig. 8. Section of a monobutton ionizer. 1. molybdenum base; 2. pyrolytic tungsten mounting; 3. pyrolytic tungsten joint.

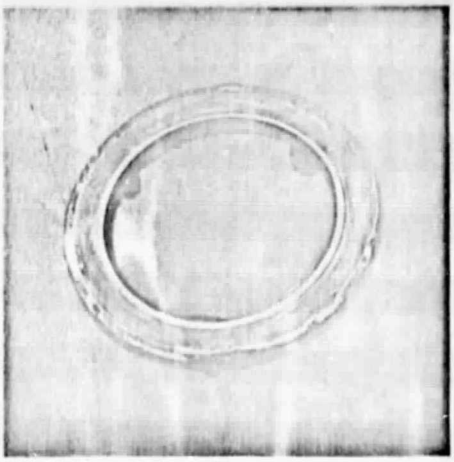

Fig. 9. Annular ionizer

V - Heating Apparatus

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The very rapid increase in the ionization coefficient with temperature is followed by a thermal threshold called the "critical temperature T_c" beyond which ionization becomes almost total. So as not to increase the heating power dissipated by radiation the ionizer surface temperature must be kept as uniform as possible, not exceeding more than 50° at any point, i.e. the critical temperature.

The necessity for heating the porous wall through the mounting (by the Joule effect or by electron bombardment) requires good thermal conduction at the joint. This conditions has been verified by means of photographs taken by a heat-sensitive infrared camera. The observed difference between the center and

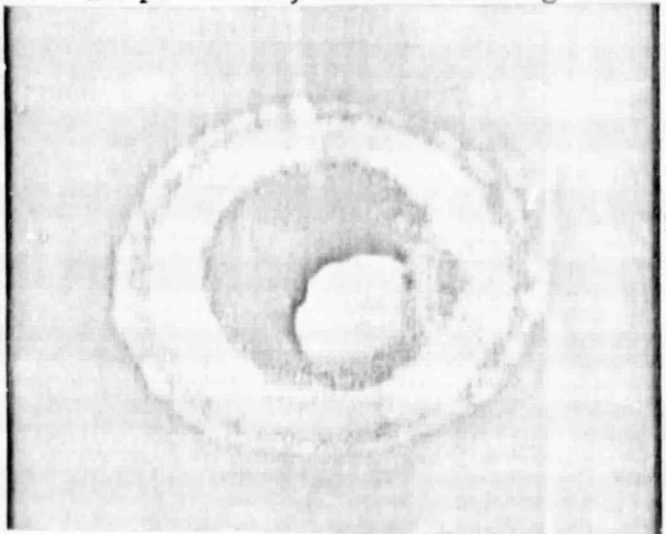

Fig. 10. Thermograph of a monobutton ionizer (thermal difference 5 K per zone).

the edge does not exceed 30°K for a mean value of 1500 K (Fig. 10) [6].

VI - Erosion of Electrodes by Slow Ions

A small quantity of neutral atoms exists in the beam in spite of the high ionization coefficient. These atoms, when struck by rapid-moving incident ions, give rise, by an exchange of charge, to slow ions which are attracted by the high positive voltage electrodes of the optical system. Here, in the long run, these slow ions can cause erosion which is not insignificant. In order to determine the amount of wear, systematic experiments have been conducted on various materials and especially on the refractory metals. Specimens constituting circular targets measuring 20 mm in diameter and heated to 600 K to facilitate degassing were subjected to bombardment by cesium ions with an /8
energy ranging between 0.5 and 3 keV.

The electron detachment coefficient (sputtering) expressed in metallic ions detached per incident cesium ion, was determined from the change in mass of the specimen after 10 hours of shooting, the number of cesium ions being calculated by integrating the current running between the generator and the target. The results obtained for molybdenum, tungsten, tantalum and niobium bombarded at an angle of 90° are shown in Fig. 11.

Observation of the surface state of the targets using a scanning electron microscope at the end of the test shows that, contrary to certain metals such as copper whose surface shows the appearance of nodules (Fig. 12 a), the surface of refractory metals exhibits uniform erosion on a microscopic scale (Fig. 12 b, c, d, e).

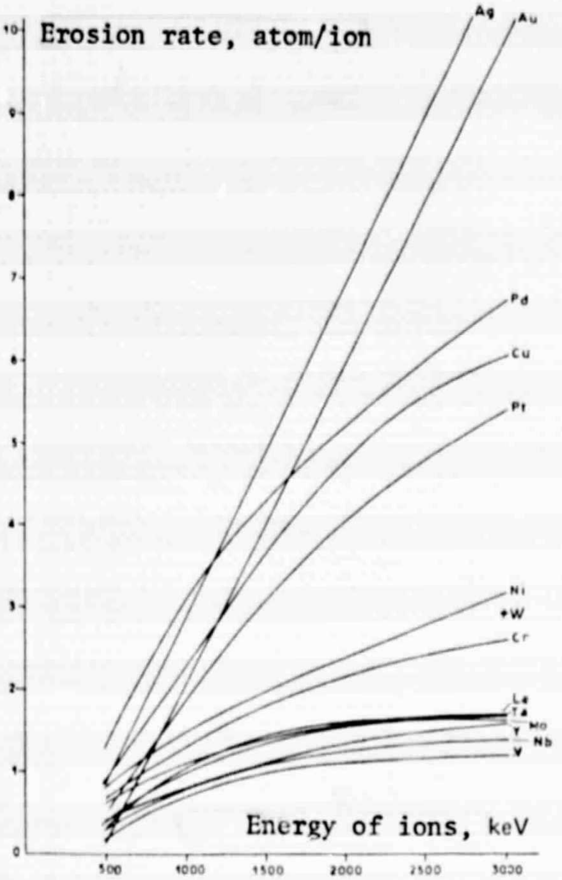

Fig. 11. Compared variation in erosion rates.

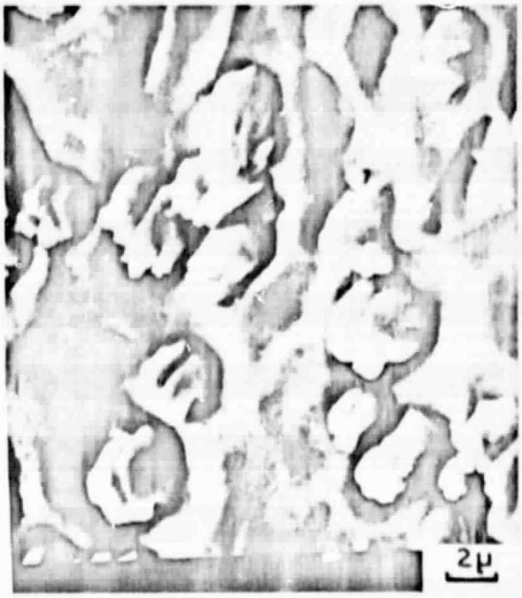

Fig. 12 a. Surface of copper after after bombardment by ions with an energy of 1500 eV.

VII - Conclusion /9

Estimation of the surface life of ionizers produced in this way has given rise to a series of tests undertaken simultaneously by CNS and ONERA in which several ionizers have been subjected either to periods of operation in a vacuum at 1450 K without cesium for several thousand hours, or to series of several dozen successive bombardments, with cesium, each for a period of 8 hours, without any change in the metallurgic properties being found. The cyclic tests were generally interrupted as a result of defects in the electric insulation.

The methods employed have led to the development of ionizers /10

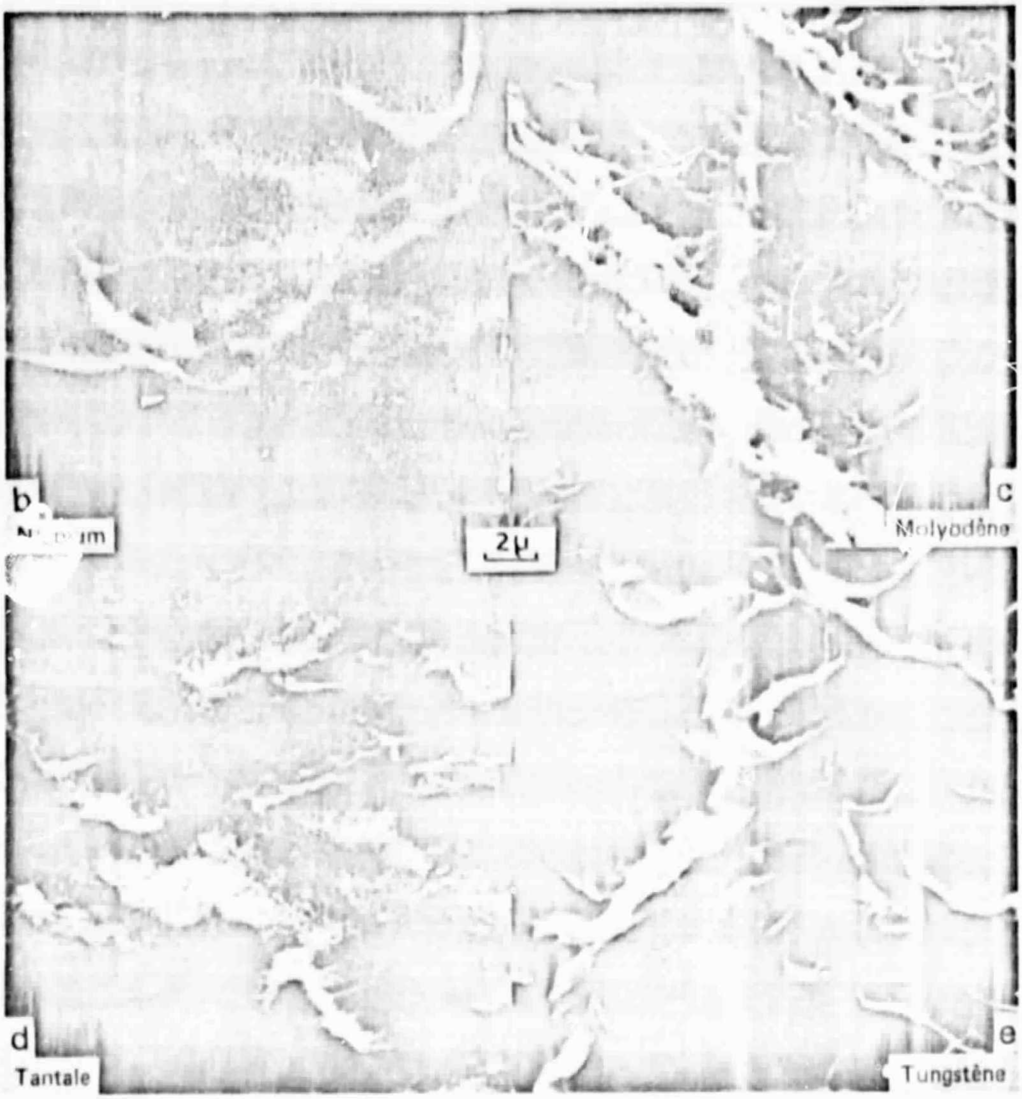

Fig. 12. Microscopic examination of specimens after bombardment by ions with an energy of 3000 V.
Key: c - molybdenum; d - tantalum; e - tungsten

having either a large emitting surface suitable for increasing the level of thrust of ion propulsion systems, or complex geometric shapes determined by calculation and which can scarcely be obtained by classical machining methods.

Beyond the realm of ion propulsion, all of these techniques can be considered as suitable for the fabrication of ion emitters designed for certain fundamental studies (e.g. standard ion sources, porous emitters for field effect ionization, etc).

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