SPARC-RF-10/001
January 12, 2010

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Activities on the sputtered metals thin films for accelerating cavity applications.

Abstract

For the next generation of linear accelerators, gradients in excess of 100 MV/m are essential in order to limit their overall length and cost. vapour

On the other hand, operating accelerating gradient in normal conducting accelerating structures is limited by RF breakdown. In order to determine the maximum gradient possibilities for normal-conducting RF powered particle beam accelerator in the framework of the collaboration with SLAC, KEK at Frascati Laboratory, an intense activity on dedicated metals coating has been started, too. To this end it has been installed a dedicated device at INFN Frascati laboratory for making the deposition technique. The aim of the present paper is to study the influence of the deposition parameters in terms of argon pressure and RF power, on the micro-structural properties of magnetron sputtering physical vapor deposition (MS-PVD) metals thin films for use in resonant cavities for particle accelerators.

Introduction

RF breakdown phenomena is complex, it limits working power and produces irreversible surface damage. The phenomena depend by many parameters like, RF circuit, structure geometry, RF frequency, input power, pulse width, pulse length, materials, surface electric and magnetic fields.

For the production of the Multi-TeV Linear Collider RF accelerating structures, a material capable of sustaining high electric field, with a low breakdown rate and showing low damages after breakdowns is needed. In the future probably film-based cavities will be operative. The reason is that, in principle, save money, since at 11,424 GHz about 600-700 nm penetration depth are really needed. Following this idea the possibility to deposit molybdenum on a copper RF cavity by means of magnetron sputtering physical vapor deposition, has been investigated, in order to find the best procedure to obtain a compact RF structure capable of sustain high electric field without breakdown phenomena.

A bulk commercial synthered molybdenum brazed RF cavity has been realized and tested at high power at SLAC[1]. Even though the main molybdenum RF parameters are little bit worse than copper one it has a higher melting point by a factor 2. For sake of completeness, molybdenum is difficult to be machined to get a good roughness (not less than 350 nm has been obtained), and it also could trap residual gas by limiting the sections performances in terms of conditioning operation and breakdown effects, as it was observed at SLAC during the high power tests on dedicated and brazed three cells section. Perhaps a dedicated powder metallurgy technique or plasma spraying could be suitable for cavities production.

For this reason, the possibility to make the cavity resonator in copper with an excellent roughness and then to deposit molybdenum by sputtering technique in order to reduce the breakdown phenomena, is under study.

Moreover, since copper and molybdenum materials have different thermal coefficients, the deposited molybdenum could be not stable rising temperature.

One possible solution, consists in depositing a film and to make a thermal treatment, about 800 Celsius degree, as preliminary test showed, in order to fix the film on the substrate (a similar treatment has been adopted for other applications)

In addition, to understand the morphological and structural aspects of the material to estimate the surfaces quality, chemical composition as a function of the depth of deposited material an activity has been planned, too.

As a first conclusion, being to be the breakdown phenomena an open field , a useful trend , of DC breakdown study , also if is not the real RF behaviour, is underway at CERN in order to test candidate materials and surface preparations [2,3]. The saturated breakdown fields of several metals and alloys have been measured, ranging from 100 MV/m for Al to 850 MV/m for stainless steel, being around 170 MV/m for Cu and 430 MV/m for Mo for example. Also possibility of depositing by the same process other materials rather than molybdenum like stainless steel or to make a RF structure using copper-tungsten alloy is going to be investigated.

In general the results reported by studying the refractory materials (molybdenum, tungsten), which seem to be able to survive higher fields than the copper usually used, tell us that they require much longer conditioning (*CERN Courier* March 2003 p6). They also reported the frequency and temperature dependence of breakdown, showing data indicating that these two parameters do not have a strong effect.

Sputtering system

Sputtering is a vacuum evaporation process which physically removes atoms from a material called the target, and deposits a thin, firmly bonded film on an adjacent surface called the substrate. The process occurs by bombarding the surface of the sputtering target with Argon ions under high voltage gradient. As these ions collide with the target, atoms or occasionally entire molecules of the target material are ejected and propelled against the substrate, where they form a very tight bond. The resulting coating is held firmly by surface forces, although, in some cases, an alloy or chemical bond may result. Vacuum coating processes use a vacuum environment and an atomic or molecular condensable vapor source to deposit thin films, typically <5µm in thickness. An example of such a process is DC Magnetron Sputtering (Fig 1 a) where material is removed from a solid target by ion bombardment and deposited on a substrate in atomic layers. It is one of the most flexible and controllable methods of generating a metal vapor in a vacuum. Applications include low friction coatings for tools, antireflective coatings on glass, decorative coatings e.g. bath taps, touch panel screens, car headlamps, telescope mirrors and coatings for photovoltaic.

An RF Magnetron Sputtering System was installed at Frascati, dedicated to:

- prepare Copper layers on metals difficult to be brazed
- deposit special metal layers on the cores to be used in the Electroforming process
- study the possibility to make Molybdenum deposition on Copper.

In the case of RF operation, the DC source in the fig. 1a will be changed by 13,56 MHz, max 1KW one.

Sputtering has proven to be a successful method of coating a variety of substrates with thin films of electrically conductive or non-conductive materials. One of the most striking characteristics of sputtering is its universality. Since the coating material is passed into the vapour phase by a physical rather than a chemical or thermal process, virtually any material can be deposited. Direct Current sputtering is used to sputter targets of conductive materials, while RF is used also for non-conductive materials.

According to our experience, preliminary studies show that molybdenum thin films deposited by RF magnetron sputtering, are friendly (and therefore less sensitive to the device) to obtain a better adhesion to the substrate than those deposited by DC magnetron sputtering with the same operational conditions, like argon pressure and RF power and also that the grain sizes of the deposited films grows by increasing of the same parameters [4].

A procedure to deposit on copper an homogeneous and very tight bond molybdenum film using a RF sputtering system has been adopted, up to now, with about some 10^{-2} mbar vacuum level and 60 W input power, the deposition thickness has been measured by FILM thickness monitor.

As reported in a previous paper [5], the results obtained with Atomic Force Microscope, in particular, show the surfaces of the machined copper with a very low roughness, of the 70 nm order, after and before the molybdenum sputtering. The undulations of the surface due to the step of lathe machine, about 700 nm, with a lots of spikes overlapped, spikes that disappear when a layer of about 100 nm molybdenum is deposited on. It seems to be that molybdenum on the copper surface acts like a smooth layer, in other words the roughness improves. Further studies are in progress in order to verify this statement.

The irises are the critical points of the higher gradient accelerating structures. On these ones we have surface fields up to 200 MV/m and a lot of damages due for instance at pulse heating and RF breakdowns.

A lot of people are studying the best material in order to reduce the spikes on their surfaces.

RF sputtering can be used to prepare special layers (gold, titanium, molybdenum and so on) in order to reduce the secondary electron emission. Some particular alloys cannot be brazed at high temperature, so sputtering and electroforming could be the best procedure to obtain these structures, without using high temperature brazing.

For instance, some sputtering tests have been reported in the figs .2-5, in order to set up the deposition procedure.

How the sputtered Molybdenum layer can modify the roughness of the base material (copper) is under study; the problem is related to the dendrite growth of the molybdenum layer that should improve the roughness.

A procedure for chemical cleaning, in order to shorten the RF conditioning time, so is crucial the cleaning level of sputtering set-up; glow discharge with Argon has been used each time before deposition in order to remove water vapour from the inside surfaces is under study .

Molybdenum sputtering on copper

In the framework of the collaboration with SLAC and KEK several samples have been realized and sent to KEK, in order to estimate the morphological and micro-structural properties of the coatings, by using Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) to determine the nature of the quality of the deposited substrate:

In particular below we report the samples to be investigated:

1 : OFHC sample with a 180 nm sputtering of Molybdenum on Cu, 750 Celsius degree thermal treatment per 10 minutes;

2 : OFHC sample with a 350 nm sputtering of Molybdenum on Cu, 600 Celsius degree thermal treatment per 10 minutes;

3 : OFHC sample with a 600 nm sputtering of Molybdenum on , 750 Celsius degree thermal treatment per 10 minutes.

Conclusions

Morphological characterizations are essential for determining the coating technique improvements and the coating quality before of the RF tests; studies are in progress in collaboration with KEK and SLAC laboratories.

The influence of deposition parameters, argon pressure, RF power and geometrical set up between target and substrate, on the micro structural and surface mechanical properties of MS-PVD molybdenum thin films for normal resonant cavities for particle accelerators will be analysed by SEM and AFM techniques and described in a forthcoming paper.

Other materials to be sputtered, like stainless steel, gold and so on are under investigation.

References

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Figure captions:

Fig. 1a Schematic diagram of a DC magnetron plasma source.

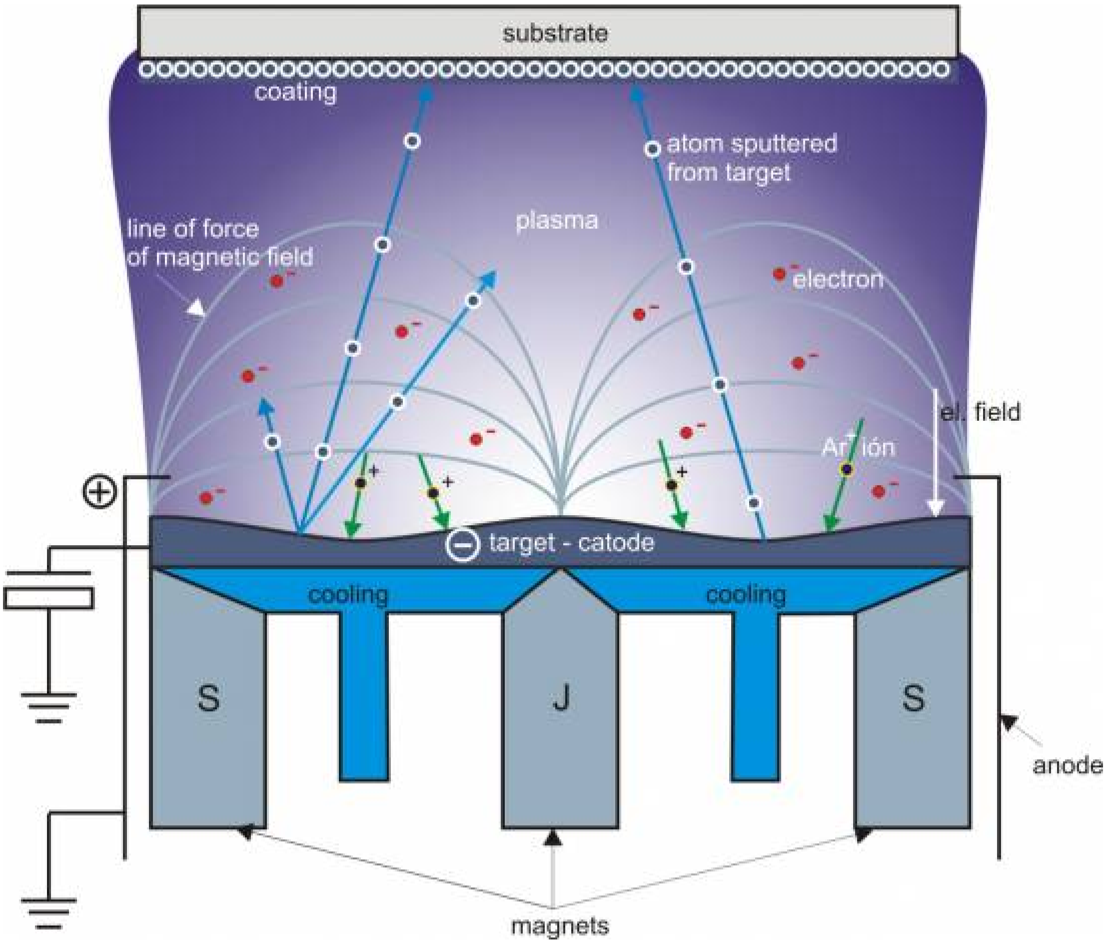
Fig. 1 Experimental set up for the RF Magnetron Sputtering .

Fig. 2 A titanium steel screw covered with copper film .

Fig. 3 An aluminium dish treated with copper .

Fig. 4 Two euro cents covered with aluminium .

Fig. 5 Aluminium cylinder covered with gold .



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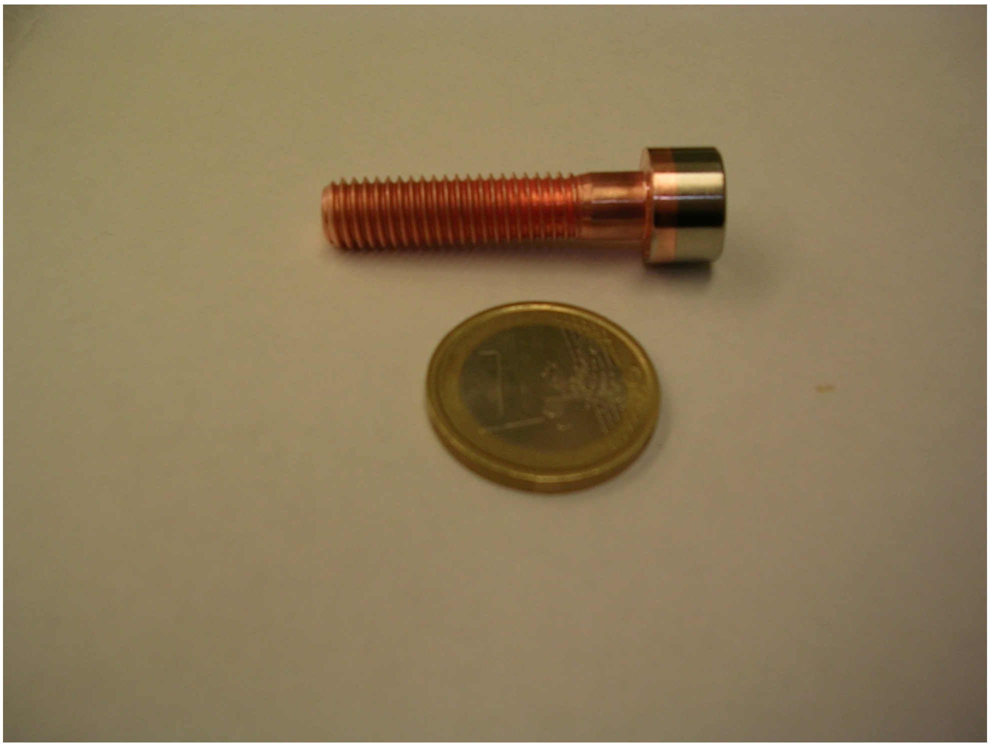

Fig. 2 A titanium steel screw covered with copper film .

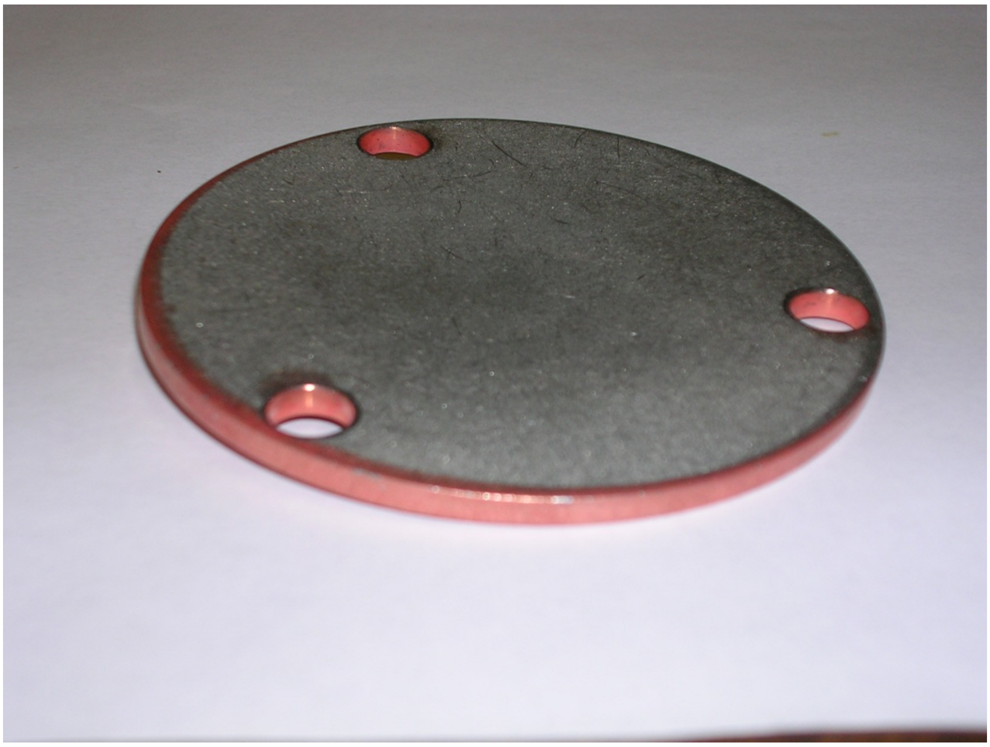

Fig. 3 An aluminium dish treated with copper

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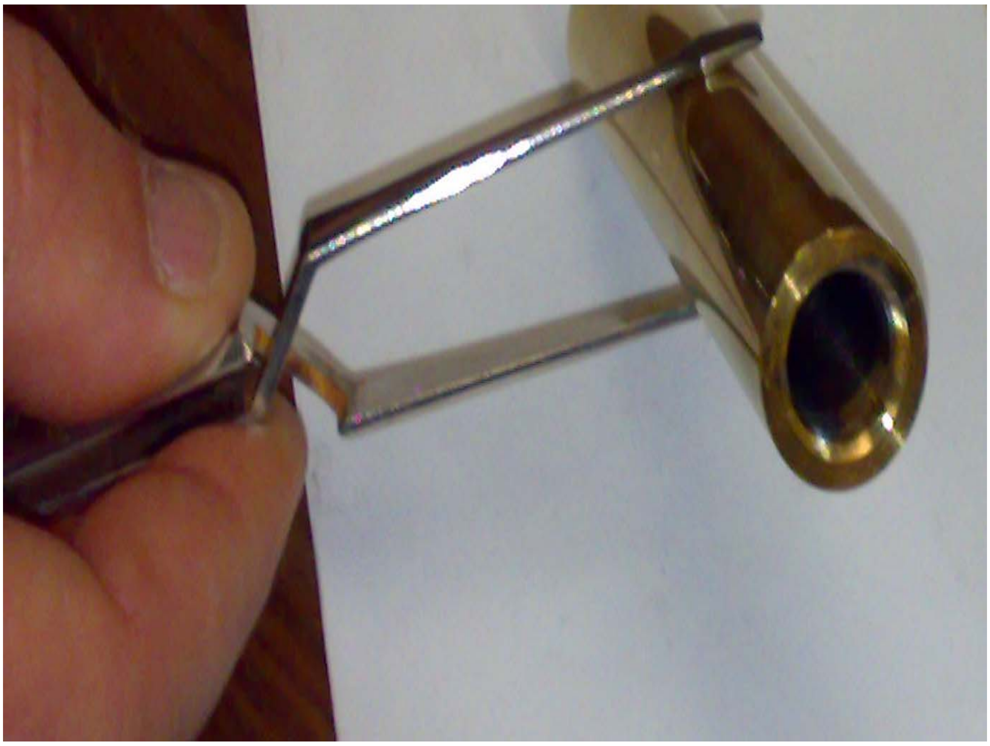

Fig. 5 Aluminium cylinder covered with gold .