SPARC-RF-09/005
November 5, 2009

Surface modifications of copper RF structure induced by dense X ray beam

S. Bini[1], S. Dabagov [1], I. Davoli [2], D. Hampai [1], M. Lucci [2] B. Spataro[1],

[1]: INFN -LNF Via Enrico Fermi 40, 00044 Frascati (Roma)
[2]:Scienza dei Materiali - Dipartimento di Fisica - Universita' di Roma " Tor Vergata"- Via della Ricerca Scientifica 1, 00133 Roma

Abstract

As known interaction of intense radiation with solids can change essentially its surface characteristics. In this work we have presented the first results of our studies on irradiation of the Cu RF structures by dense X-ray beams. X-ray microbeam shaped by means of polycapillary semilens has been applied as a probe in a number of specified stripes on a surface. The_indentation depth analysis has shown the change in surface hardness in correspondence to the applied radiation dose.

Introduction

It has been seen that the microscopic surface status plays an important role on the maximum gradient limiting for Cu X-Band RF accelerating structures (Sami Tantawi private communication), and not only from a point of view of surface roughness or cleanliness but also considering the metallurgical behavior of the material. This could be explained considering that the metal (as well as its alloys) structure undergoes some modifications after repeated thermal cycles, for instance, increasing the grain size. In this case, a boundary region builds up between contiguous grains. This region can be considered like a fracture in metal crystalline structure. These fractures could be the sources of hot spots, which might generate the discharges.

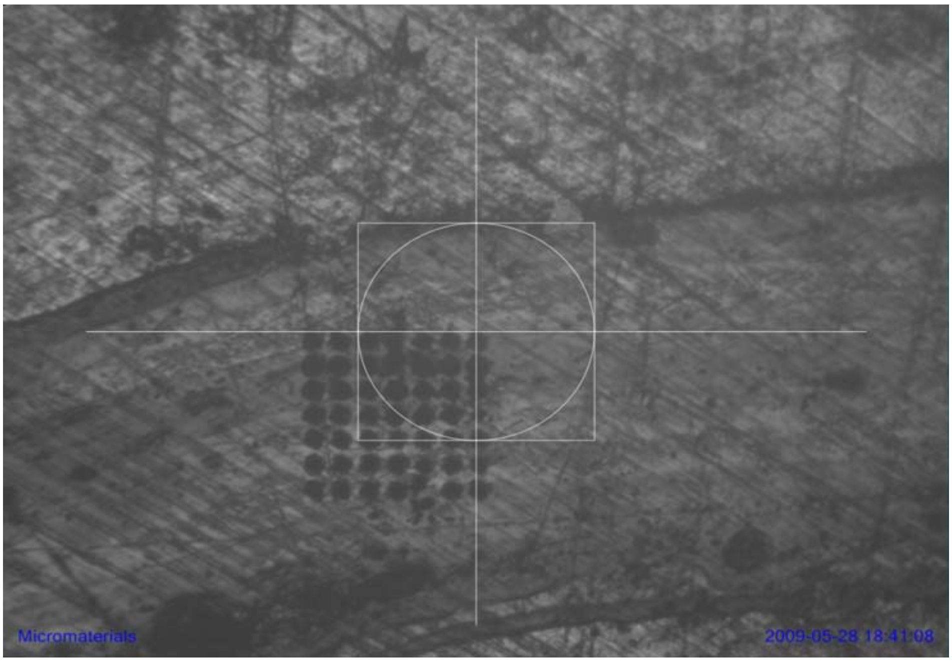
Unfortunately, during the manufacturing process of the Cu RF structures the high temperature brazing process produces very high thermal stress that brings to the strong increase of the material grain size. This process can be reduced by means of either low temperature (T<250°C) soldering procedure or adopting a special surface treatment.

However, we can consider another possible solution, which strongly correlated with the second option described. Apart of the surface treatment for controlling the grain size that is typical temperature effect, the strong radiation flux can produce another very interesting feature. If intense radiation flux will be applied to the surface for very short period of time (that takes typically place due to very short interaction time, for instance, for X-ray processes in solids), like explosion near the surface, the physics of interaction becomes similar to that of mechanical interaction. Successfully, so strong impulse of radiation force applied to the surface can produce well-known shock waves. In turn, the latter might be of strong interest due to its ability to change the surface characteristics of studied solids.

The purpose of this work intends to explore the feasibility of the solution based on surface irradiation procedure.

Basics

Soft X-rays are typically absorbed by near surface layer of irradiated object of 0.01 μm; the process duration can be estimated of the order of a few fs that is much shorter than any mechanical intercation. X-ray interaction leads to evaporation of the surface layer of substance and appearance of shock waves under the operation of recoil momentum.



The evidence of irradiation effect on a Cu surface

The method for simulating the mechanical effect due to "the explosion" of thin surface charges is mainly based on the asymptotic solution of plane shock wave propagation. Given method makes possible to reproduce the impact parameters wave close to actual conditions, at the equality of the pulse of simulating interaction to the recoil momentum, if the initial length of shock wave is much lower than the thickness of the obstacle. Thus, using well-known technique to describe mechanical intercation to the surface we can simulate in the first approximation all the processes of high-flux X-ray radiation intercation with a surface.

Procedure and results

As a first preliminary run, some Cu samples were irradiated with intense X-ray radiation flux (~20 keV, $10^{10\text{-}11}$ ph/s) using a standard X-ray source whose radiation was concentrated on the sample by means of polycapillary optics, namely by polycapillary half lens. We have used a microfocus X-ray tube (Mo K_α, 30 kV, 1 mA) with a source dimension of less than 100x100 μm^2, a polypicapilary optics optimized for 15-20 keV: the focal dimension of about 140x140 μm^2 with a transmission of about 23%. In order to get a strip (specially irradiated area) of 1 mm length and of 0.2 mm width (that is bigger than our spot dimension), we fixed the sample out of the focus. By this way, we have reached a spot of 200x200 μm^2. The holder movement is remote controlled via PC in combination with a Newport hardware: the actuators with a resolution of about 1 μm. For each sample, we have chosen three different irradiation times for each step of 100 μm: 5, 10 and 15 minutes.

After irradiation, the samples surface hardness was checked for the evidence of any changes.

The mechanical properties have been characterized, at room pressure and temperature, by standard

nanoindentation tests (NanoTest, Micro Materials Ltd., U.K.) using a three-faced pyramidal Berkovich diamond indenter. The experiments were performed applying a load and measuring the indentation depth. The applied load was 200 mN with a rate of 5mN/s and the depth reached was about 3000 nm. Each result is obtained with a 7x7 indentations about 30 um spaced to obtain a 200x200um matrix on the irradiated area. An example of data, load Vs depth, used to extrapolate the information about hardness and module are shown in fig x.

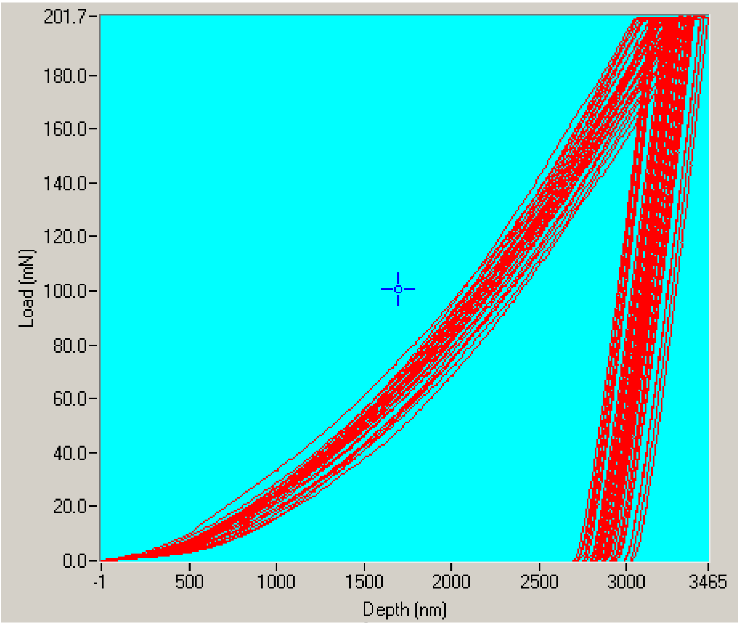


Fig X

The first results (preliminary test) are as follows:

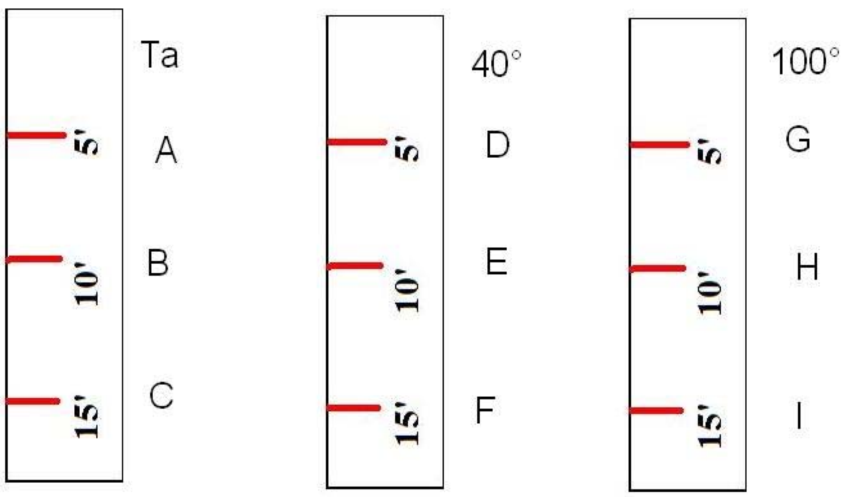
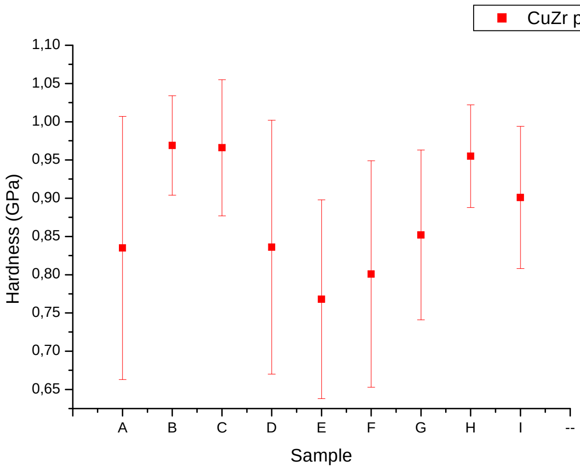


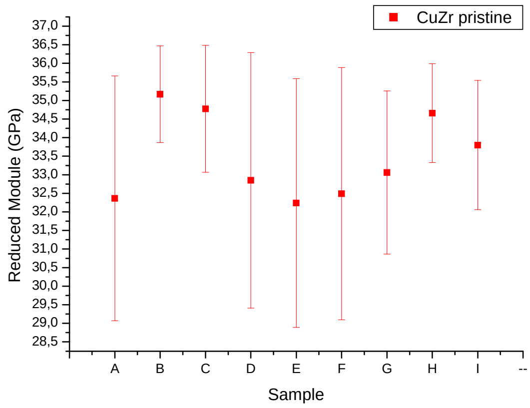
Fig xx

In figxx is shown the scheme of tree samples (Ta, 40°, 100°) irradiated at room temperature, at 40° and 100° respectively. Each sample was irradiated for 5, 10 and 15 minutes in the red region showed in the pictures.
In order to verify only the heating influence we measured the samples near each irradiated area and we use this value to normalize the each measure.

Sample TA		Hardness (GPa)	Error +- (GPa)	Reduced Module (GPa)	Error +- (GPa)
A pristine		0,835	0,172	32,366	3,295
B pristine		0,969	0,065	35,168	1,302
C pristine		0,966	0,089	34,775	1,708
A		0,877	0,123	33,107	2,297
B		0,941	0,101	34,550	1,879
C		0,894	0,082	33,166	1,607
Nome file	Sample 40°	Hardness (GPa)	Error +- (GPa)	Reduced Module (GPa)	Error +- (GPa)
D pristine		0,836	0,166	32,850	3,439
E pristine		0,768	0,130	32,240	3,350
F pristine		0,801	0,148	32,490	3,394
D		0,636	0,126	28,850	2,730
E		0,845	0,103	33,100	2,078
F		0,550	0,184	27,280	4,890
Nome file	Sample 100°	Hardness (GPa)	Error +- (GPa)	Reduced Module (GPa)	Error +- (Gpa)
G pristine		0,852	0,111	33,060	2,198
H pristine		0,955	0,067	34,660	1,328
I pristine		0,901	0,093	34,800	1,740
G		0,901	0,053	33,926	1,240
H		0,903	0,087	34,285	1,679
I		0,859	0,060	33,205	1,205

Table 1


CuZr pristine
Hardness (GPa)
1,10
1,05
1,00
0,95
0,90
0,85
0,80
0,75
0,70
0,65
A B C D E F G H I --
Sample


CuZr pristine
Reduced Module (GPa)
37,0
36,5
36,0
35,5
35,0
34,5
34,0
33,5
33,0
32,5
32,0
31,5
31,0
30,5
30,0
29,5
29,0
28,5
A B C D E F G H I --
Sample

FIGee

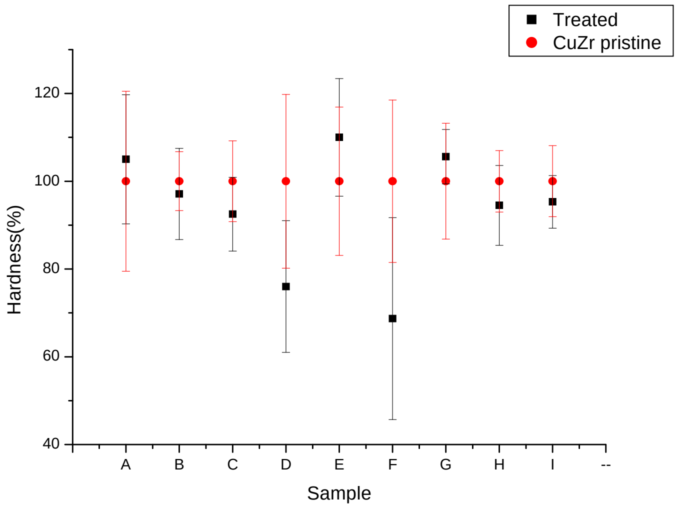

Treated
CuZr pristine
Hardness(%)
120
100
80
60
40
A B C D E F G H I --
Sample

fig H

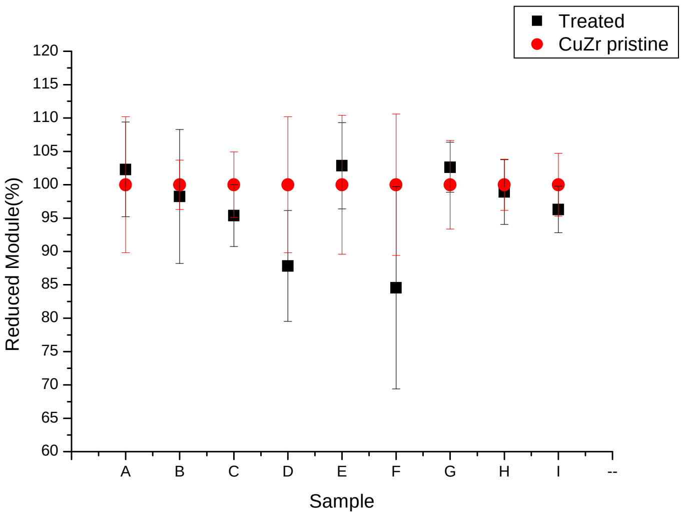

Treated
CuZr pristine
Reduced Module(%)
120
115
110
105
100
95
90
85
80
75
70
65
60
A B C D E F G H I --
Sample

fig RM

Analyzing the results of the mechanical characterization, table 1, we can deduce that the heating without irradiation don't affect the hardness and reduced module of the samples, fig. ee.
In fig H, are showed the normalized hardness obtained by indentation experiment, the red dot are the normalized hardness of each pristine areas near the irradiate spots,
Reduced Module normalized is plotted in fig RM , the red dot are the normalized values of each pristine areas near the irradiate spots.
On sample "Ta" we can deduce a little reduction of the both Hardness and Reduced module with the increasing of time exposition, this reduction is very little because the overlapping of results considering the error. In the sample heated at 40° the reduction of the mechanical properties is more evident.
The results obtained on sample "100°", considering the error, indicate that the treatments, i.e. irradiation and heating, do not affect the mechanical properties.

Future

It is important to create a special code for simulating the process of high-flux radiation interaction with a surface. This will allow the RF preparation to be optimized from the point of view of our interest and its applications. Of course, it is necessary to develop the procedure of irradiation used during first preliminary run; it should be optimized by the width of a strip, for instance.