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3 MeV proton irradiation effects on surface, structural, field emission and electrical properties of brass

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ABSTRACT

Ion-induced modifications of brass in terms of surface morphology, elemental composition, phase changes, field emission properties and electrical conductivity have been investigated. Brass targets were irradiated by proton beam at constant energy of 3 MeV for various doses ranges from 1×10^{12} ions/cm^2 to 1.5×10^{14} ions/cm^2 using Pelletron Linear Accelerator. Field Emission Scanning Electron Microscope (FESEM) analysis reveals the formation of randomly distributed clusters, particulates, droplets and agglomers for lower ion doses which are explainable on the basis of cascade collisional process and thermal spike model. Whereas, at moderate ion doses, fiber like structures are formed due to incomplete melting. The formation of cellular like structure is observed at the maximum ion dose and is attributed to intense heating, melting and re-solidification. SRIM software analysis reveals that the penetration depth of 3 MeV protons in brass comes out to be 38 µm, whereas electronic and nuclear energy losses come out to be 5×10^{-1} and 3.1×10^{-4} eV/Å respectively. The evaluated values of energy deposited per atom vary from 0.01 to 1.5 eV with the variation of ion doses from 1×10^{12} ions/cm^2 to 1.5×10^{14} ions/cm^2. Both elemental analysis i.e. Energy Dispersive X-ray spectroscopy (EDX) and X-ray Diffraction (XRD) supports each other and no new element or phase is identified. However, slight change in peak intensity and angle shifting is observed. Field emission properties of ion-structured brass are explored by measuring I-V characteristics of targets under UHV condition in diode-configuration using self designed and fabricated setup. Improvement in field enhancement factor (β) is estimated from the slope of Fowler-Nordheim (F-N) plots and it shows significant increase from 5 to 1911, whereas a reduction in turn on field (E_o) from 65 V/µm to 30 V/µm and increment in maximum current density (J_{max}) from 12 µA/cm^2 to 3821 µA/cm^2 is observed. These enhancements in field emission characteristics are correlated with the growth of surface structures, specifically agglomers which are responsible for electric field convergence. Electrical by four probe method has been correlated with maximum current density and decreasing trend is observed with increasing ion doses.

1. Introduction

During the last decades the growing interest is developed to modify the materials by ion irradiation [1]. Ion-beam irradiation can modify surface, electrical, optical, compositional, mechanical and field emission properties of the materials according to industrial and scientific applications [2,3]. The growth of various kinds of structures like hillocks, pores, clusters, ripples, agglomers, droplets, fibre and cellular like structures is reported in the literature after ion implantation. The growth of these various kinds of features is explainable on the basis of coulomb explosion [4], thermal spike model [5], cascade growth [6] and Ostwald ripening effect [7]. Ion-induced surface modification and its correlation with field emission properties is scarcely reported. Brass surface, structure and mechanical properties after 2 MeV ion irradiation at various fluences has been studied by Ahmad et al. [8]. Pure copper (Cu) has been irradiated with Cu ions at a constant energy of 14 MeV, stacking fault and displacement damage in the form of black spot clusters are studied by Zinkle et al. [9]. Brass is the most widespread Cu alloy in which Zinc (Zn) is present as alloying element. Due to combination of distinctive properties it has tremendous applications in electrical, aerospace, automotive and precision engineering industries [10]. Ion irradiation can grow localized structures on treated surfaces which can enhance their field emission properties. Eventually these emitters are preferred in numerous applications e.g. Field Emission Scanning Electron Microscope (FESEM), flat panel display, space-vehicle neutralization, microwave generation, X-ray generation and e-beam lithography [11,12]. Field emission emitters exhibits F-N type tunneling which is described by wave-mechanical tunneling of electrons via

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deformed surface triangular barrier in the presence of high electric field [12]. Reduction in turn-on field, increased emission current and convergence of electric field at grown structures by ion irradiation is observed [3]. Chen et al. [13] modified ultra-nanocrystalline and microcrystalline diamond films by 100 MeV ion irradiation with ion fluence of 5×10^{11} ions/cm^2. As a result nano-cluster network is grown that becomes a source of improvement in F.E parameters. According to our best knowledge no work is reported in which enhanced F.E parameters of brass by ion irradiation has been performed. Our aim is to make a correlation between enhancement in F.E properties with surface morphology after ion irradiation of brass which includes growth of clusters, agglomers, droplets, fibre and cellular like structures. Ion modified surface of brass have been analyzed in term of surface morphology by FESEM, elemental composition by EDX and XRD, electrical conductivity by four probe method and FE properties by measuring I-V characteristics under planer diode configuration.

2. Experiment setup

2.1. Ion irradiation setup

Circular shaped brass targets of diameter 10 mm and thickness of 6 mm were wire cut from commercial brass rod. The samples were grinded and polished by using SiC papers and were ultrasonically cleaned by acetone for 10 min. Pelletron Linear Accelerator (6SDH-2-NEC USA) installed at Centre for Advanced Studies in Physics (CASP), Govt. College University, Lahore, Pakistan. It was used as ion-implanter to irradiate brass targets. Proton ion beam of size 2×2 cm^2 with 3 MeV constant energy is used for treatment. Proton doses of 1×10^{12} ions/cm^2, 5×10^{12} ions/cm^2, 1×10^{13} ions/cm^2, 5×10^{13} ions/cm^2 and 1.5×10^{14} ions/cm^2 have been used to irradiate five brass targets for the duration of 30 s, 150 s, 300 s, 1500 s and 4500 s respectively, with corresponding average beam current of 21.36 nA. Whereas, proton beam current density is 5.34 nA/cm^2 for all irradiated targets. We have varied doses and time duration of irradiation while keeping beam current and current density as the constant factors at room temperature under UHV condition.

2.2. Field emission setup

In order to explore enhancement in field emission properties of proton-irradiated brass, the self-designed and fabricated field-emission set-up was used which is schematically shown in Fig. 1. The setup consists of stainless chamber in which structured electrodes are placed under ultra high vacuum condition i.e. 10^{-8} torr via diode configuration. Circular shaped untreated target was considered as anode while all treated targets were regarded as cathode. Spacing distance between these electrodes is held constant for all measurements. i.e. 200 µm. High electric field was employed by using DC voltage source (Matsusada, AU, 100P∗6, 100 kV, 6 mA). In order to limit the current, a resistance of vacancies, agglomeration of vacancies in form of clusters and dislocation of line density was placed in series with the anode. To measure I-V characteristics an electrometer (Keithley 2400) was used which is placed after 125 KΩ resistance.

2.3. Characterizations techniques

Surface morphology, elemental composition, structural analysis (phase purity), and electrical conductivity of untreated and treated targets were investigated by using Field Emission Scanning Electron Microscope (FESEM) equipped with energy dispersive X-ray spectroscopy EDX (Model Nova Nano-SEM 450) and XRD (X-Pert PRO MPD). Four probes alignment is very sophisticated technique for measuring discrepancy in electrical nature of the material by employing high current source. It consists of Keithley 6220 DC current source and Keithley 2182A nano voltmeter. Single target is placed under the four respective probes which consist of outer and inner probes. Outer probe is used to apply current while inner probe give assistance in measuring voltage.

3. Results and discussion

3.1. Field emission scanning electron microscope

Field Emission Scanning Electron Microscopic (FESEM) images of Fig. 2 reveal the surface morphology of (a) untreated and proton beam treated brass targets at different ion doses of (b) 1×10^{12} ions/cm^2, (c) 5×10^{12} ions/cm^2, (d) 1×10^{13} ions/cm^2, (e) 5×10^{13} ions/cm^2 and (f) 1.5×10^{14} ions/cm^2. Images of Fig. 3 are corresponding magnified view of Fig. 2. In Figs. 2 and 3, (b) low density and randomly distributed diffused clusters and agglomers are seen at the lowest dose. When the ion dose is increased up to 5×10^{12} ions/cm^2 in Figs. 2 and 3, (c) more prominent, well defined, distinguished and large sized circular shaped agglomers and droplets are formed. With further increase in the ion dose up to 1×10^{13} ions/cm^2 in Figs. 2 and 3, (d) the size of particulates, droplets and agglomers is significantly reduced, whereas their

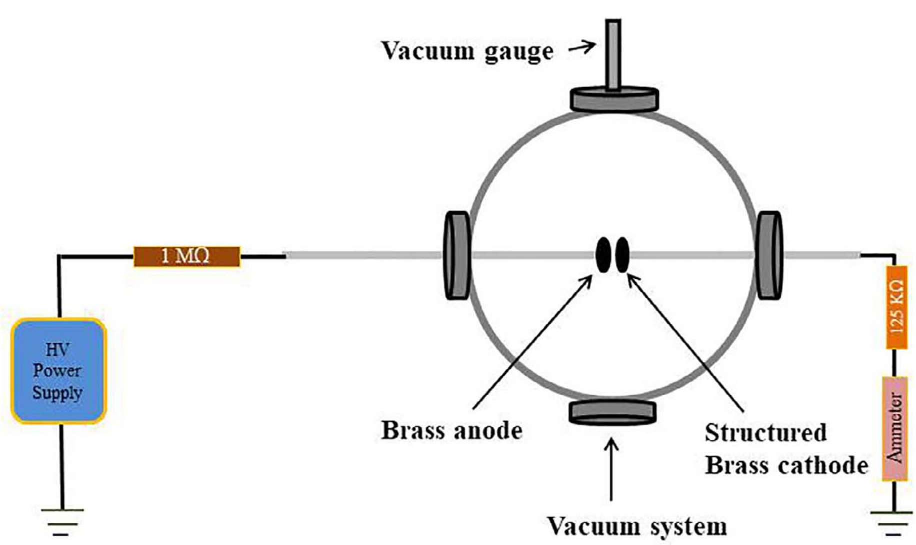

Fig. 1. The schematic diagram of self-designed and fabricated experimental setup to measure field emission properties of ion irradiated brass together with UHV chamber, high voltage power supply and ammeter.