6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Conical pattern formation on atomically heterogeneous surface by microwave plasma generated low energy ion irradiation for field emission study

Jayashree Majumdar and Sudeep Bhattacharjee
Department of Physics, Indian Institute of Technology Kanpur (IITK), Kanpur 208016, India
e-mail (speaker): jaymaj@iitk.ac.in

The growth of surface structures of micro-submicro-nano dimension due to ion irradiation is an important field of research in material processing studies. Such surface structures are produced due to surface atoms removal and rearranging themselves as self-organized patterns, which cause increase in surface porosity and surface area [1]. When irradiated with inert gaseous ions, the exposed surfaces become compositionally heterogeneous at the atomic length scale [2]. The electrical, optical and surface properties of atomically heterogeneous systems with micropattern arrays, produced on metallic surface by high fluence of energetic inert ions irradiation, have been investigated in literature [2-5].

An elaborate comparative study is performed on conical arrays of atomically heterogeneous, self-organized, micro-submicro-nano dimensional copper structures synthesized by high flux of 2 keV argon (flux = 6.47 x 10^{15} cm^{-2} s^{-1}) and krypton ions (flux = 4.81 x 10^{15} cm^{-2} s^{-1}) at normal incidence. We have obtained various types of surface structures for variation over wide range of ion beam fluence that can be described as conjoined mounds, prominent pyramidal structures, mosaic mounds, sharp conics etc. as observed from scanning electron micrograph (SEM) and atomic force micrograph (AFM). Krypton ion irradiation at very high fluence of 5.76 x 10^{18} cm^{-2} revealed almost complete absence of abovementioned structures due to sputtering related erosional damage. However, as an interesting observation their transmission electron micrographs (TEM) revealed distinct nodular penetration below the amorphous layer which may be caused due to krypton ion irradiation-induced bubble formation. Substantial amount of presence of argon and krypton ions in absence of any metallic seeding agent is verified from X-ray photoelectron spectroscopic analysis.

There is potential for the ion irradiated surface patterns formed on bulk copper, to act as naturally selected micro/nano field electron emitter source. Hence field emission experiment is performed on substrate irradiated at optimized fluence range where prominent conical tips are obtained on repeated experimentation. These field emitter conical arrays find application in vacuum electronics as field-emission displays, electron microscopes, electron guns etc.

Jensen's theoretical analysis gives idea of the local field at the apex of rotationally symmetric hyperbola and the emitter current is calculated. The calculation is then extended over an array of uniformly shaped emitters by using parameters like number of emitters and distribution factor associated with spread of tip radii [6].

In naturally formed field emitters, the structures are not uniformly distributed and also there is significant variation in local field over the slope of these structures.We have formulated a theoretical model based on statistical distribution of uniformly dimensional conical arrays to compare with the experimentally obtained conical protrusions. The presence of implanted ions needs to be incorporated to properly explain our experimental findings.

References

[1] I. Tanyeli, L.Marot et al., Scientific Reports, 5 9779, p 1-9 (2015).
[2] S. Chatterjee, S. Bhattacharjee, S. K. Maurya et al. EPL, 118, 68006 (2017).
[3] K.P. Singh, J. Majumdar and S. Bhattacharjee. Applied Optics,59,4507-4515 (2020).
[4] A. Chowdhury, S. Bhattacharjee. AIP Adv 1, 042150 (2011).
[5] J. Majumdar and S. Bhattacharjee. Frontiers in Physics, 9, 310 (2021).
[6] K.L. Jensen. Applied Physics Letters (1996).

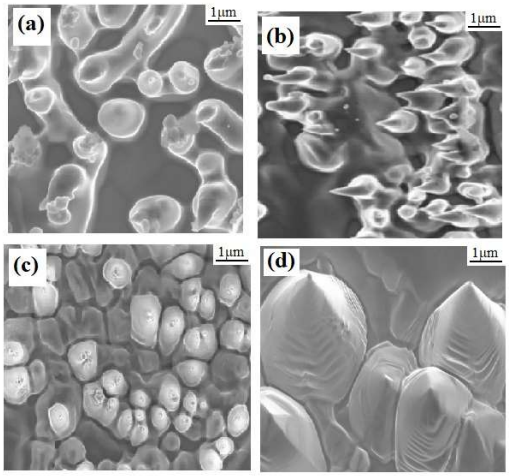

Figure 1: SEM image (5 μm × 5 μm scan area) of (a) conjoined mounds and (b) sharp conics observed by argon ion irradiation at fluence of 2.12 x 10^{18} cm^{-2} and 3.95 x 10^{18} cm^{-2} respectively. Krypton ion irradiation produces (c) mosaic mounds and (d) pyramidal structures at fluence of 2.59 x 10^{18} cm^{-1} and 3.58 x 10^{18} cm^{-1} respectively.

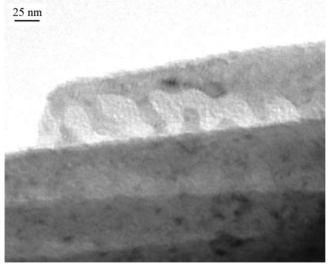

Figure 2: Cross Sectional TEM view of copper surface irradiated by krypton at 5.76 x 10^{18} cm^{-2}