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Formation of nanoscale metallic structures on cupric nitride thin film surface by the impact of 200 MeV Au^{15+} ions

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Abstract

Cupric nitride films deposited on borosilicate glass and Si substrates by RF reactive sputtering are irradiated by 200 MeV Au^{15+} ions from Pelletron accelerator. On-line elastic recoil detection analysis (ERDA) technique shows a large depletion of N (~75% depletion) from the films due to electronic sputtering effect of heavy ion whereas the copper content remains unchanged. This observation is associated with a sharp rise in sample ladder current signifying an enhancement of electron emission from the film during irradiation. The surface of the as deposited film studied by atomic force microscope (AFM) shows nanodimensional grain formation. Conducting AFM (CAFM) measurements show that at certain regions (10–30 nm) of the irradiated film surface a rapid rise of current (~9000 pA) takes place. Enhancement of electron emission together with conducting AFM measurements lead us to conclude that conductivity of the surface enhances due to formation of nanodimensional metallic zones under Au ion impact. The entire process is understood on the basis of thermal spike model of ion–solid interaction.

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Keywords: Nanometallic structures; ERDA; Electronic sputtering; AFM; CAFM; Thermal spike

1. Introduction

One of the most fascinating enterprises of modern physics is to exploit materials of dimensions less than 100 nm for miscellaneous applications [1–5]. The idea of making "nanostructures" comprising of few atoms has great appeal, both as a scientific challenge and for practical reasons. In recent years scientists have shown various techniques for building nanostructures, which can be classified broadly in two parts, (i) top-down and (ii) bottom-up approach. Top-down method carves out or adds aggregates of molecules to a surface whereas bottom-up method assembles atoms or molecules into nanostructures. Photolithography, soft lithography, etc. are among the important examples of top-down approach whereas bottom-up method describes setting up carefully controlled chemical reactions to assemble atoms and molecules in order to make nanostructures. Both these approaches have their own advantages and disadvantages. Following the philosophy "Let thousand flowers bloom" adopted by nanofabrication researchers extensive works are going on in different laboratories to fabricate nanostructures by various techniques.

Copper nitride is one of the important covalent metal nitride compounds and has been scarcely studied. The decomposition of this material into elements due to low thermal stability suggests its possible use in metallization reactions, which could be of significant importance in the

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electronics industry. The feasibility of using these films to generate metal lines by maskless laser writing is explored recently [6–8].

Swift heavy ion (SHI) has unique property to engineer materials down to nanoscale [9–11] dimension. SHI, when impinges on materials excites and ionizes the electronic subsystem and this energy is eventually transferred to phononic subsystem via a complex electron–phonon coupling mechanism [12]. The thermal energy so developed in the lattice leads to the formation of nanodimensional defects in the perturbed lattice [12]. Some important findings in this respect are (i) annular and tubular arrays of nanoprecipitates in thermal spikes from swift heavy ion [9], metallic nanorods by MeV ion beam induced plastic deformation [13], clusters of C and Si aligned in a column of about 5–10 nm [10], alignment of Ag nanoparticls in the columns along the ion track [11]. Electronic sputtering, i.e. erosion of materials from the surface due to the impact of SHI on material is a current state of research [14,15]. It has been observed by our group that a large depletion of N takes place from copper nitride (Cu_3N) thin films under irradiation of 200 MeV Au^{15+} ion [16], whereas the content of Cu remains unchanged. The electronic sputtering yields as calculated from ERDA data is ~800 N atoms/ion and it strongly depends on the grain size of the films [16]. The result was explained on the basis of the effect of transient thermal spike on the lattice due to ion impact, which causes depletion of nitrogen. An idea of confinement of thermal energy inside the smaller grains has also been discussed. It is well known that copper nitride like other binary nitrides decomposes due to thermal energy [17].

In the year 1993, it has been shown by Maya [17] that micron size metallic structure can be formed in copper nitride films by laser. The explanation was given [17] on the basis of laser heating and subsequent depletion of nitrogen from the copper nitride film as it decomposes at higher temperature.

Stimulated by the work of Maya et al. and with our knowledge of electronic sputtering of nitrogen under SHI irradiation we plan for the present work to generate nanosize metallic structures on copper nitride films. On-line elastic recoil detection analysis (ERDA) is employed to determine the yield similar to our earlier study [16]. The crystalline phase of the film is identified by grazing angle X-ray diffraction (GAXRD) technique. Surface morphology is analyzed by atomic force microscope (AFM). Conducting AFM study is performed to see the surface conductivity of the irradiated film.

2. Experiment

The experimental processes can be discussed in the following sections.

2.1. Deposition of thin films

Copper nitride thin films (thickness ~ 90 nm) are deposited on borosilicate glass and silicon substrates by radio frequency (13.56 MHz) reactive sputter deposition technique. A schematic of deposition setup is given in Fig. 1. The deposition process is same as described in our earlier work [18].

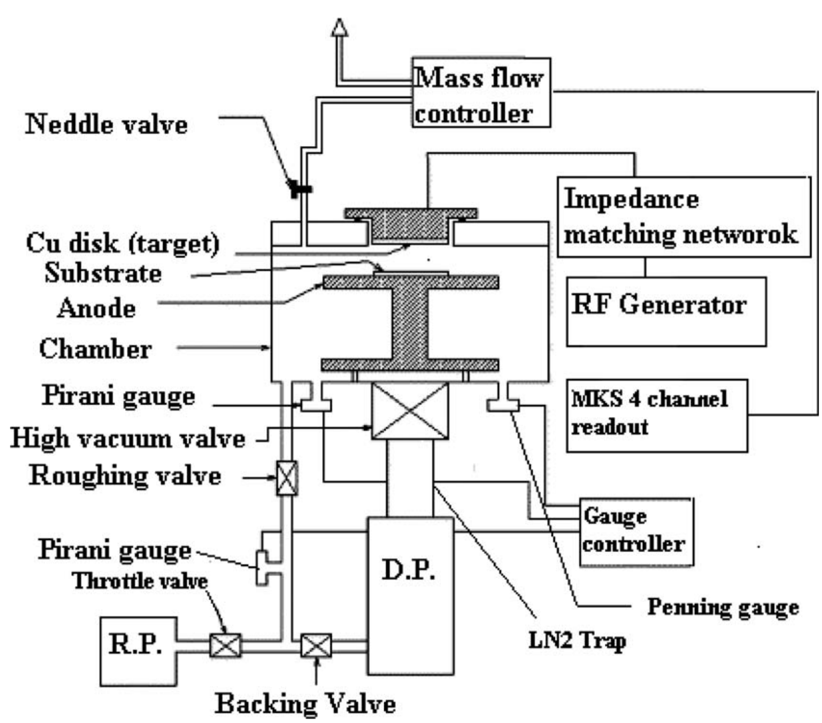

Fig. 1. Schematic diagram of RF sputtering setup.