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Mechanism of elongation of gold nanoparticles embedded in silica glass

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Gold nanoparticles aligned with the same distance are fabricated in silica using the method of electron beam lithography. When swift heavy ions are irradiated to it, elongation of gold nanoparticles toward the same direction to the ion propagation direction was observed. Elongation length of gold nanoparticles depends on ion flux, fluence and energy. Temperature as a function of penetration time was calculated by the thermal spike model. When simulated temperature exceeds to melting temperature of silica glass and gold, elongation of gold nanoparticles was observed.

I. Introduction

It has been reported that gold nanoparticles embedded in silica glass are elongated with ion beam irradiation. The first observation of gold elongation was in core-shell colloids composed of a 14nm diameter Au core surrounded by a 72nm thick silica shell. After irradiation with 30MeV Se ion at a fluence of 5×10^{14}cm^{-2}, elongation of gold nanoparticle was observed.[1] We learned from the following reports that this phenomenon is not simple. For example, Rizza et al. used 15±2 nm Au NCs are embedded within a 500 nm silica layer and all the Au NCs are in a plane at 200 nm below the surface of the silica film.[2, 3] They used 4 MeV Au ions for fluences up to 2.2×10^{16} cm^{-2}. Size of original gold nanoparticle decreased with increasing number of small particles surrounding an original particle. This phenomenon depends on size of gold nanoparticle as well as the energy of the ion beam. In this article, the dependence of flux, fluence and ion energy on behavior of gold nanoparticle is examined. Also, temperature of silica and gold nano particles with the thermal spike model was simulated.

II. Experimental,

Silicon substrates with a 2 μm-thick amorphous SiO_2 (a-SiO_2) were used. A 50 nm-thick layer of ZEP520 resist coated a-SiO_2 before curing. Nanoscale patterns were drawn on the resist by electron beam lithography. Subsequent development produced nanoscale holes in the resist on the a-SiO_2 substrate. The substrate was then mounted in an evaporator and a 0.5 nm-thick Cr layer was deposited for adhesion of a 40 nm-thick layer of Au. Finally, the resist was removed by treatment with acetone to leave an Au nanoparticles on the a-SiO_2 substrate. The Au nanoparticles were then embedded in a-SiO_2 by depositing a second layer of silica by sputtering. The thickness of the top layer of a-SiO_2 was 200 nm.

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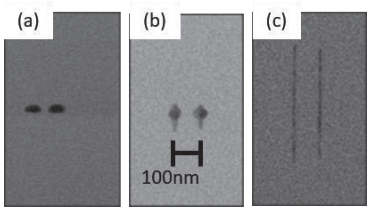
The final assemblies were irradiated with 110 MeV Br^{10+} ions. A beam current of 100 nA corresponded to *(*2.8 ± 0.3*)* $\times 10^{11}$ cm^{-2} s^{-1}. The direction of propagation of the ion beam was perpendicular to the upper surface of the a-SiO_2. Cross-sections of the pristine and irradiated samples were examined by transmission electric microscopy (TEM).

To elucidate the mechanism of the elongation of the gold particles, the thermal spike model is used to simulate the evolution of the temperature around the swift heavy-ion path.

III. Results

Dependence of Au nanoparticles on the flux density of the ion beam at a constant fluence was examined. Figures 1 (a)-(c) show Au nanoparticles with a diameter of 40nm in SiO_2 before irradiation (a) and after irradiation with 110 MeV Br^{10+} ions at flux densities of 3×10^{10} cm^{-2} s^{-1} (b) and 6×10^{10} cm^{-2} s^{-1} (c) at a fluence of 2×10^{14} cm^{-2}. The aspect ratio of nanorods increased with increasing flux density. Au nanoparticles with a diameter of 70nm embedded in SiO_2 were also prepared and irradiated with 110 MeV Br^{10+} ions. Fluence and flux for an Au nanoparticle with a diameter of 40nm are the same as that for for an Au nanoparticle with a diameter of 10nm nanoparticles.

Lattice temperature of Au nano particles with radii of 5 and 10 nm embedded in SiO_2 are calculated. In the case of a nano particle with a radius of 5 nm, the temperatures of the Au nano particle monitored 1 and 3.5 nm from the center exceed the melting point of Au (1337 K). The maximum temperatures at both distances also reach the melting point of SiO_2 (1992 K). A point 6.5 nm from the center of an Au nano particle of radius 5 nm is located within the SiO_2 matrix. The temperature at this point increases dramatically 5 fs after ion impact, and exceeds the melting point of SiO_2 for the period between 20 fs and 10 ps after the ion impact. The lattice temperature 10 nm from the center of the nano particle does not exceed the melting point of SiO_2.



Figures 1 Au nanoparticles embedded in a-SiO_2 before irradiation (a). After irradiation with 110 MeV Br^{10+} ions at flux densities of 3×10^{10} cm^{-2} s^{-1} (b) and 6×10^{10} cm^{-2} s^{-1} (c) at a fluence of 2×10^{14} cm^{-2}.

IV. Summary

We prepared Au nanoparticles with a constant distance and embedded in SiO_2. A nano particle with a diameter of 40nm was elongated in contrast, a nano particle with a diameter of 70nm was not observed elongation. The experimental results well correspond to simulation of lattice temperature.

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