Ion beam induced stress at the nanoscale

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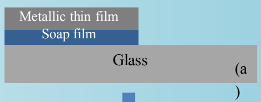
Introduction & Motivation

Ion beam can produce significant amount of stress upon irradiation on metallic crystalline structure. The developed stress can change the morphology of the surface through reconfiguration processes. Such processes have been successfully used to produce surface patterning and have been an exciting area so far. On the other hand, irradiation effect on nanoscale object can be different due to its smaller dimension. Change of shape and size of such nano object of different materials has been observed by various studies. Controlled manipulation of nanostructures by using focused ion beam is a promising technique for manufacturing futuristic micro/nano devices.

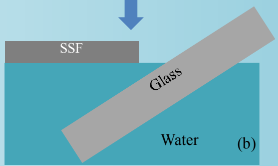
Cantilever fabrication and Ion Induced Bending

- A dual-beam FIB system (Nova 600 NanoLab) having a 5-30 keV Ga ion beam has been used to perform the experiments.
- Self-supporting thin film (SSF) of 50-200 nm was fabricated using the following process:

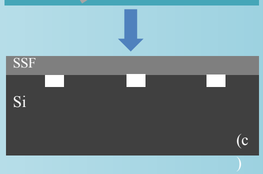
(a) Thin film is deposited on soap coated glass substrate using a thermal evaporation unit



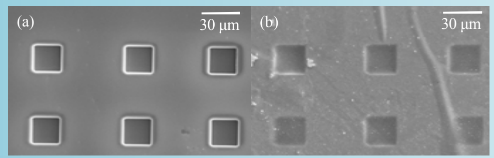
(b) The sample is then immersed in water to separate out the metallic thin film from the glass substrate. The SSF floats on water.



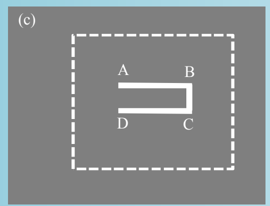
(c) The SSF is lifted and placed on top of a Si surface on which there are few prefabricated trenches (white colored in the figure).



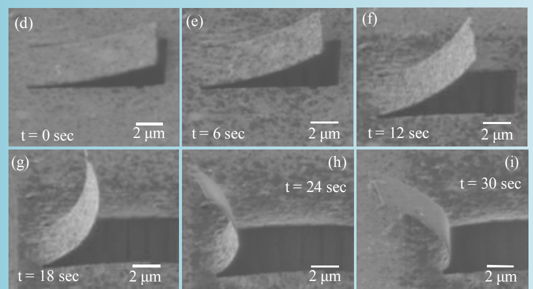
- The SSF shows polycrystalline nature as revealed by X-ray diffraction study.
- The prepared sample was further taken inside the FIB chamber for further experiment.



SEM is extensively used to detect the trenches which are now covered by the SSF. A SEM picture shows the image (top view) of (a) trenches fabricated on a Si silicon, (b) the trenches covered by the SSF.



Schematic picture shows the fabrication procedure of a cantilever. The cantilever is fabricated at the mid of the SSF by milling out the portion along the AB, BC and CD line (figure c). The dotted line indicates the location of the trench.
A SEM image of a cantilever fabricated using the above procedure is shown in figure (d) below.

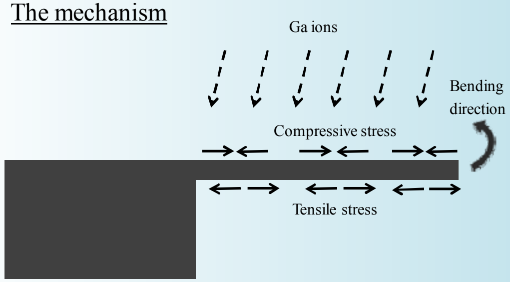


Ion beam is irradiated on the cantilever. The cantilever tends to bend towards the ion beam side.

Scanning ion microscope (SIM) snapshots captured at different stages of the ion-beam-induced bending of a typical Ag nanocantilever. The irradiated angle was 52° and the beam energy was 30 keV.

Mechanism and Applications

The mechanism

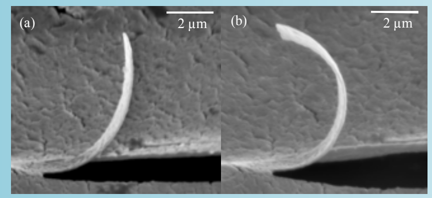


Defects, vacancies are formed at the surface of the cantilever by the ions. The unstable/perturbed atoms at the top layers try to reconfigure themselves, generating different amounts of stress in different layers of the system.

The reconfiguration process initiates the bending of the structure.

Annealing effect on ion irradiated metallic cantilever: Releasing residual stress

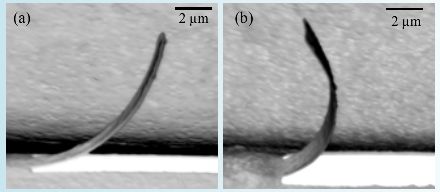
(a) By furnace heating



Before annealing

After annealing

(b) By e-beam heating

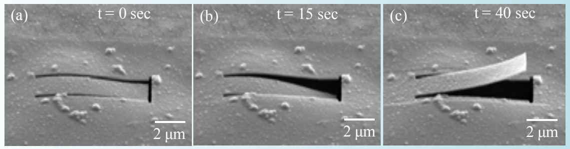


Before irradiation

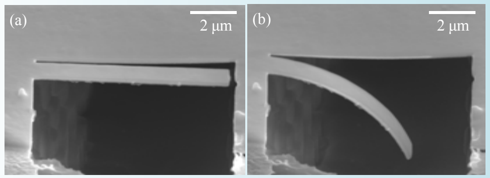
After irradiation

Bending of bilayer (amorphous-metallic) film:

Case I: Upon ion irradiation



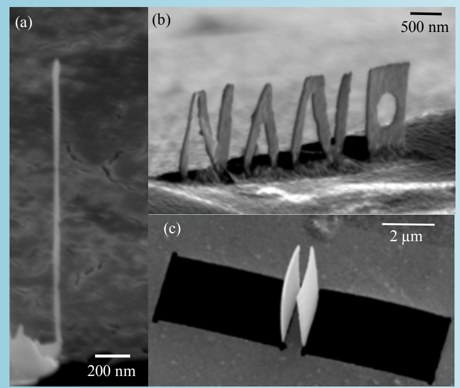
Case II: Upon electron irradiation



- Ion as well as electron beam can produce significant amount of heat during irradiation.
- In case of bilayer film (amorphous-metallic), the temperature has been found to play the dominate role in the bending of the bilayer structure.
- Thermo-induced plastic expansion process of the amorphous layer has been expected to cause a downward bending of the bilayer cantilever.

Applications of IIB

In 3D nanostructuring



(a) nanowire, (b) Nano script, (c) parallel plate

Other applications

- The technique can be used as a ***mass sensor*** to measure mass of the femtogram order.
- It can also be used for lifting heavy mass (e.g. in futuristic ***nanocrane devices***).
- Also in fabricating prototype modules/devices like ***nanomechanical switches***, parallel plate ***capacitors***, parallel plates for ***detecting charged particles***, ***micro***/***nanovalves*** for controlling fluid flow, etc.

Summary & Conclusions

- Ion beam induced stress at the nanoscale has been studied and used for 3D nanostructuring.
- Bending of bilayer (amorphous-metal) film has been explained on the basis of thermo-induced plastic deformation of the amorphous layer.
- Annealing experiments shows the presence of residual stress in the structures.

References

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