

## 1. Research Work – Summary – Dr. P. V. Satyam's Group

This has been divided in three sections:

1. Ion – Nanostructure interactions: fundamental study and their applications
2. Soft-Condensed Matter Physics: Polymers and LB films (composite films)
3. Collaborative work on TEM using other groups (where our contribution is significant to the extent of TEM imaging and quantitative analysis, interpretation in the context of paper, etc.).

### (I) **Fundamental understanding of Ion – Nanostructure interactions and their applications:**

My group has contributed and made a mark in the study of ion – nanostructure interactions. After a span of six years work in this area, and by studying various aspects (crater formation, nanosilicide formation, embedding, dramatic mass transport under high flux condition, strain determination, etc.), we are at a reasonably good place to understand what happens when ion impinges on nanostructures. In the process, we have also established as one important group in cross-section electron microscopy.

In semiconductor physics, metal – semiconductor interfaces play a major role as these are used in ohmic contacts, Schottky barriers, wafer – bonding, gettering process etc. But all these studies involve continuous and uniform layers. Our main work is on nano-structure – silicon interfaces. Most of our studies are concentrated on nano gold or silver on silicon substrates. The nanostructures were formed using vacuum deposition of thin layers or/and using molecular beam epitaxy or/and chemical methods. Ion irradiation effects on these Au and Ag nanostructures have been studied in detail. We have also studied irradiation effects on nano Au – Ge systems, Ge quantum dots (grown using MBE), Co/Si and Ni/Ge systems.

Our experimental results show dramatic mass transport induced by ion bombardment from the nanostructures into the substrate. For this, the amorphization in the substrate matrix plays a very important role: Gold diffusion in amorphous silicon is six orders of magnitude higher than that in crystalline silicon. Hence, we started our study with amorphization of Silicon under MeV Au ion bombardment and recently flux dependent studies showed a new way of understanding mass transport of nanostructures. At high flux, low fluence condition, we have observed enhanced diffusion compared to the initial size of the nanostructures. The interesting thing is that, in our studies no additional step of annealing is required to form metastable crystalline alloys. At higher fluencies and high flux conditions, disassociation of gold silicide leading to the segregation of gold atoms to the surface of silicon substrate has been observed. We proposed a defect dependent mechanism to understand these studies.

## **II. Soft-condensed matter: polymers, LB films**

We have setup the soft-condensed matter laboratory about a three years back with an aim to understand the nanostructure growth on patterned polymer and Langmuir-Blodgett films. One of the major focuses is on understanding the bottom up approach. In this direction, we are working on nanostructure growth on patterned polymer/LB films. Initial measurements were carried out on Ge microstructure growth patterned surfaces. Patterning was carried out using ion micro-beam facility at our Institute and followed with evaporation of Ge on the patterned surfaces. Patterning has also been done using focused ion beam (Ga ion beam) on silicon substrates and plans for UHV growth on these surfaces is in progress. Major proposal in 11<sup>th</sup> plan was to study on this aspect, and for this purpose a combined system of field emission gun based scanning electron microscope and focused ion beam along with in-situ gas injection systems would be procured soon (hopefully in few months time). One of my student's thesis works is based on the organization of various nanostructures in the polymers (e.g. polymer nano-composite) and their control under heat treatment. We showed that gold nanoparticles dispersed better when post-polymerization step is carried out. In these studies, Gold nanoparticles are first prepared and then incorporated with styrene and followed with polymerization step to make nano-dispersed polymer films. In our recent studies, gold nanostructures were also formed in polymers using low energy ion implantation. TEM and UV-Vis absorption studies have been carried out on these systems as well.

We have installed NIMA LB setup and have been successful in making good self-organized long chain LB films. In some cases, gold nanostructures were added in the sub-phase and then transferred LB films supported on carbon coated films to study the size distribution and the structure of the nano particles. Also, the dynamic studies on self-organization of gold nano particles as a function of various temperature using in-situ TEM studies are in progress.

## **III. Collaborative work with other groups:**

We have a very strong collaborative program within the Institute and outside the Institute. My group helps many external users in carrying out high resolution TEM, explanation of these results in the context of the research.

Within the Institute, the collaborative work was concentrated on two areas:

- (a) Study of quantum structures grown using MBE (Prof. B. N. Dev's group) and
- (b) Study of ion beam mixing in multi-layered thin films (with Dr. T. Som's group). Many interesting results have been observed in the above areas where the use of TEM had been very explicit and essential.

Outside the Institute, collaborative work was active on the high resolution electron microscopic study of filled carbon nanostructures. Structural characterization of the Ni and Co filled multi-walled carbon nano tubes with and without ion irradiation effects (Prof. D. S. Misra's group in IIT – Mumbai) has been experimentally studied. The research work carried out with our collaborative program was important input for one of the Ph.D. thesis student of Prof. D. S. Misra (Dr. P. K. Tyagi).

A strong collaborative program with Dr. B. Sundaravel and Dr. K. G. M. Nair has helped one of my Ph.D. student to carry out high-energy high current irradiation studies at IGCAR, Kaplakkam. Details on this work have been given in the part I and also in the following. The work carried at IGCAR is a major part of student thesis work (Mr. J. Ghatak's thesis work).

Under the Indo-Japan bilateral exchange program, collaboration with Prof. Akimoto (of department of quantum engineering, Nagoya university, Japan) and Prof. Emoto (of Toyota National College of Technology, Toyota), a detailed study of strain and at surface and interfaces of single crystalline silicon under the ion bombardment has been studied. MeV ion beams have been used to create strain and defects in the silicon and (in thin films on silicon substrates), and asymmetric x-ray diffraction studies have been carried out using the facilities at Photon factory at KEK, Japan. Our combined effort has helped to establish asymmetric x-ray rocking curve measurements as a good tool to study the strain at surface and interfaces. High resolution microscopy results are used to complement these x-ray results.

With collaborative program and using the facilities at Argonne National Laboratory (USA) (collaboration with the groups of Prof. S. K. Sinha and Dr. J. Wang and Dr. R E Cook of MSD), we have carried out detailed studies on RF sputtered thin films (using RBS and XTEM), and various studies on the effects of radiation damage on polymeric films (PtBA, PMMA and PS). Some of these studies are part of my student's thesis (Mr. Umananda). Collaborative work on studying nanostructures using high resolution microscopy with Prof. D. D. Sarma (IISc/IACS), late Prof. S. Choudhary (IACS), Dr. Murali Sastry (NCL/Tata Chemicals, Pune), Dr. B L V Prasad (NCL, Pune), Prof. Narayana Rao (University of Hyderabad), Dr. Anjan Gupta (IIT – Kanpur), Prof. A. Roy (IIT – Kharagpur), Prof. N. C. Mishra (Utkal University), Dr. Kanjilal (IUAC, New Delhi), Dr. D. Khulshani (TIFR, Mumbai), yielded many interesting studies. In all the collaborative works with these groups, detailed TEM studies have been carried out by my group and the analysis of the TEM data had been very useful for the structural characterization of various studies.

## Details of the Work:

### (a) Ion – Induced amorphization in Silicon:

[J. Kamila et al., Nucl. Instrum. Methods Res. B 207 (2003) 291]

The amorphization due to MeV Au<sup>2+</sup> ion implantation in Si(111) has been studied using Rutherford backscattering spectrometry/channeling (RBS/C) and transmission electron microscopy (TEM) methods. 1.5 MeV Au<sup>2+</sup> ions were implanted into Si(111) substrates at various fluences at low currents (0.02–0.04  $\mu\text{Acm}^{-2}$ ) while the samples were kept at room temperature. The RBS/C results for as-implanted specimen shows the onset fluence for amorphization to be  $5 \times 10^{13}$  ions  $\text{cm}^{-2}$  which is much lower than the fluence reported earlier. Selected area diffraction (SAD using our TEM) for a sample implanted at a of  $1 \times 10^{14}$  ions  $\text{cm}^{-2}$  confirms the occurrence of the amorphization.

### (b) Crater Formation:

[Ref: P. V. Satyam et al., J. Appl. Phys. **93** (2003) 6399]

The modification of gold nanoislands, grown on silicon substrates under high-vacuum conditions, by MeV self-ion irradiation has been studied. Upon irradiation with 1.5 MeV Au<sup>2+</sup>, two types of craters are observed on the Au islands: Empty craters and craters with a central hillock. The contribution of plastic flow, pressure spike, and sputtering to the crater formation during the ion impacts on the gold islands is analyzed. This was the first publication by using our high resolution TEM facility.

### (c) Energy spike induced effects in MeV ion-irradiated nanoislands:

[B. Satpati et al., Nucl. Instrum. Methods Res. B 212 (2003) 157]

Upon irradiation with 1.5 MeV Au<sup>2+</sup> ions, interesting observations were found for the nanoislands in comparison with continuous films: (i) higher probability of crater formation, (ii) larger sputtered particle size as well as coverage and (iii) enhanced sputtering yield. Crater formation has been studied as a function of impact angle at a fluence of  $1 \times 10^{14}$  ions  $\text{cm}^{-2}$  and we found that crater formation is prominent at high impact angles (i.e. at glancing angle geometry). AFM has been used to determine the crater formation, TEM to study the sputtered particles as well as craters and RBS has been used to determine the sputtering yield from the nanoisland and continuous films.

### (d) Study of sputtered particles from gold nano-islands due to MeV self-ion irradiation:

[B. Satpati et al., Nucl. Instrum. Methods Res. B 212 (2003) 332]

The sputtered particles are collected on catcher grids (carbon coated) during the irradiation and are analyzed with TEM and RBS. The average sputtered particle size is determined from TEM measurements, whereas the amount of gold on the catcher grid is found by RBS. The average sputtered particle size from thin (up to

a thickness of  $\approx 2$  nm) discontinuous films is larger compared to the average particle size from thick continuous films. The coverage of the sputtered particles on the catcher grids is also discussed. Energy spike and its distribution in the nano-islands is proposed to be the main reason for the variation in the particle size and the coverage of the sputtered particles on the catcher grid.

**(b) Nanoscale ion-beam mixing in Au–Si and Ag–Si eutectic systems:**

[Ref: B. Satpati, et al. Appl. Phys. **A79** (2004) 447]

MeV ion induced mixing in the nanoscale regime for Au and Ag nanoislands on silicon substrates have been studied. Au and Ag nanoislands are grown on silicon substrates at room temperature and irradiated with 1.5-MeV  $\text{Au}^{2+}$  ions at various fluences. We observe a metastable mixed phase for the Au–Si system at a fluence of  $1 \times 10^{14}$  ions  $\text{cm}^{-2}$ , while no mixed phase is formed for the Ag–Si system. For both Au–Si and Ag–Si systems, a part of the islands is pushed into the substrate. The mixed phase of the Au–Si system is found to be crystalline in nature. The higher eutectic temperature and lower heat of mixing of the Ag–Si system compared to the Au–Si system could be responsible for the lack of mixing and silicide formation in the Ag–Si system. High resolution TEM has been effectively used to determine the phase formation.

**(c) Ion-beam-induced embedded nanostructures and nanoscale mixing**

[Ref: B. Satpati et al., J. Appl. Phys. **96** (2004) 5212]

Cross-sectional transmission electron microscopy and Rutherford backscattering spectrometry are used to study the ion-beam mixing in Au/Si systems. At a fluence of  $1 \times 10^{14}$  ions  $\text{cm}^{-2}$ , a material push-in effect and a metastable Au-Si phase formation have been observed for Au nanoislands, while no push in or mixing has been observed for the case of continuous films. The mixed phase of Au-Si system is found to be crystalline in nature. We used to aquaregia to show that non-reacted gold signal exists after irradiation. It has to be noted that these measurements are carried out using low flux irradiations. At higher flux values, mixing has been observed and this will be explained later in this section.

**(d) Size distribution of sputtered particles from Au nanoislands due to MeV self-ion bombardment:**

[Ref: B. Satpati, et al. J. Appl. Phys. **98** (2005) 064904]

Nanoisland gold films were irradiated with 1.5 MeV  $\text{Au}^{2+}$  ions up to a fluence of  $5 \times 10^{14}$  ions  $\text{cm}^{-2}$  and at incidence angles up to  $60^\circ$  with respect to the surface normal. The sputtered particles were collected on carbon-coated grids during ion irradiation and were analyzed. The average sputtered particle size and the areal coverage are determined and the amount of gold on the substrate is found. The size distributions of larger particles number of atoms/particle,  $n \geq 1000$  show an inverse power law with an exponent of  $-1$  in broad agreement with a molecular-dynamics simulation of ion impact on cluster targets.

**(e) MeV ion-induced strain at nanoisland-semiconductor surface and interfaces:**  
[Ref: J. Ghatak et al. Nucl. Instrum. Methods Res. B 244 (2006) 64]

Strain at surfaces and interfaces play an important role in the optical and electronic properties of materials. MeV ion-induced strain determination in single crystal silicon substrates and in Ag (nanoisland)/Si(111) at surface/interfaces has been carried out using transmission electron microscopy (TEM) and surface-sensitive X-ray diffraction. Irradiation has been carried out with 1.5 MeV Au<sup>2+</sup> ions at various fluences and impact angles. Selected area electron diffraction (SAED) and lattice imaging (using TEM) has been used to determine the strain at surface and interfaces. Preliminary results on the use of surface-sensitive asymmetric X-ray Bragg reflection method have been discussed. The TEM results directly indicate a contraction in the silicon lattice due to ion-induced effects. The nanoislands have shadowed the ion beam resulting in lesser strain beneath the island structures in silicon substrates. High-resolution lattice imaging has also been used to determine the strain in and around amorphization zones caused by the ion irradiation.

**(f) Energy dependent sputtering of nanoclusters from a nanodisperse target:**  
[Ref: B. Satpati et al. Nucl. Instrum. Methods Res. B 244 (2006) 278]

Au nanoparticles, prepared by thermal evaporation under high vacuum condition on Si substrate, are irradiated with Au ions at different ion energies. During ion irradiation, embedding of nanoparticles as well as ejection of nanoclusters is observed. Ejected particles due to sputtering are collected on carbon-coated grids. Both the grids and the ion-irradiated samples are analyzed with transmission electron microscopy (TEM) and Rutherford backscattering spectrometry (RBS). Size distribution of the sputtered Au clusters on the TEM grids for different ion energy regimes are presented. In the case of low energy (32 keV) ions, where the nuclear energy loss is dominant, sputtering is less as compared to medium energy (1.5 MeV). In the high-energy regime (100 MeV), where the electronic energy loss is dominant, sputtering is found to be maximum.

**(g) Characterization of ion beam induced nanostructures:**  
[Ref: J. Ghatak et al. Nucl. Instrum. Methods Res. B 244 (2006) 45]

Tailoring of nanostructures with energetic ion beams has become an active area of research leading to the fundamental understanding of ion–solid interactions at nanoscale regime and with possible applications in the near future. Rutherford backscattering spectrometry (RBS), high resolution transmission electron microscopy (HRTEM) and asymmetric X-ray Bragg-rocking curve experimental methods have been used to characterize ion-induced effects in nanostructures. The possibility of surface and sub-surface/interface alloying at nano-scale regime, ion-beam induced embedding, crater formation, sputtering yield variations for systems with isolated nanoislands, semi-continuous and continuous films of noble

metals (Au, Ag) deposited on single crystalline silicon will be reviewed. MeV-ion induced changes in specified Au-nanoislands on silicon substrate are tracked as a function of ion fluence using ex situ TEM. Strain induced in the bulk silicon substrate surface due to 1.5 MeV Au<sup>2+</sup> and C<sup>2+</sup> ion beam irradiation is determined by using HRTEM and asymmetric Bragg X-ray rocking curve methods. Preliminary results on 1.5 MeV Au<sup>2+</sup> ion-induced effects in nanoislands of Co deposited on silicon substrate will be discussed.

**(h) Strain distribution due to ion implantation revealed by extremely asymmetric x-ray diffraction:**

[Ref: T. Emoto et al, e-J. Surf. Sci. Nanotech. **4** (2006) 25]

Lattice strain of Si(111) implanted 1.5 MeV Au<sup>2+</sup> ion was investigated by extremely asymmetric x-ray diffraction. The measured rocking curves were consisted of a bulk peak and a broad sub peak accompanying with intensity oscillation. Analysis of the strain distribution was done by fitting of the measured curve with curves calculated by a dynamical diffraction theory. The resultant strain profile shows introduction of a tensile strain in extent of 500 nm. Comparing the strain profiles with the distributions of the projected range and the vacancy calculated by the TRIM code, it was concluded that the lattice strain is contributed by not only the defect due to collision event but also the interstitials of Au ion. In addition, we found that the global shape of the broad sub peak is very sensitive to the strain distribution within the depth of ~80 nm.

**(i) Flux dependent MeV ion induced modification of nano-Ag/Si system:**

[Ref: J. Ghatak et al. Nucl. Instrum. Methods Res. B (2008) (In Press)]

Thin films of Ag (1.5 nm thick) are grown on Si (111) substrates using evaporation method in high vacuum condition and due to non-10 wetting nature of silver, isolated islands of mean size ~12.0 nm have been formed on the surface. Au<sup>2+</sup> (1.5 MeV) ions have been used to irradiate the above systems at various fluences ( $5 \times 10^{13}$ – $1 \times 10^{15}$  cm<sup>-2</sup>) at an impact angle of 5° and at a flux of  $6.3 \times 10^{12}$  cm<sup>-2</sup> s<sup>-1</sup> (corresponding to a beam current density of 2.0  $\mu$ A cm<sup>-2</sup> for Au<sup>2+</sup> ions). Ion beam induced embedding is observed to begin at a fluence of  $1 \times 10^{14}$  cm<sup>-2</sup> for this high flux whereas low flux irradiations (current density ~0.02  $\mu$ A cm<sup>-2</sup>) of Au<sup>2+</sup> ions under similar irradiation conditions did not yield embedding (impact angle 5°). High resolution transmission electron microscopy measurement showed no mixing in the form of silicide formation. These results are compared with high flux modifications in Au/Si system.

**(j) Mass transport in ion–nanostructure interactions:**

[Ref: J. Ghatak et al. Nucl. Instrum. Methods Res. B **266** (2008) 1282]

Recently, interesting differences for ion–uniform film and ion–nanostructure interaction phenomena, particularly relating to ion beam mixing effects have been reported. Upon irradiation with 1.5 MeV Au<sup>2+</sup> ions on isolated Au

nanostructures on silicon substrate, a higher probability of crater formation, larger sputtered particle size and its coverage and enhanced sputtering yield compared to the continuous films of Au on Si substrate were observed. Ion bombardment at high flux ( $6.3 \times 10^{12}$  ions  $\text{cm}^{-2} \text{s}^{-1}$ ) showed a dramatic mass transport from nanostructures extending up to a distance of about 60 nm into the substrate, much beyond their size. In this paper, RBS/Channeling results would be presented to elucidate on the arrangement of re-distributed gold atoms location in silicon and silicide matrix. Scanning transmission electron microscopy (STEM, with high angle annular dark field imaging) was used to complement the RBS results in determining the unusual mass transport and under ion–nanostructure interaction. The amorphous nature of the silicon matrix, that is deduced from both the RBS/Channeling and from TEM measurements, is an important factor in enhanced diffusion process resulting in dramatic mass flow.

**(k) Flux dependent MeV self-ion- induced effects on Au nanostructures: Dramatic mass transport, nano-silicide formation and sputtering**

[Ref: J. Ghatak et al. Nanotechnology (2008) (under review)]

We report a direct observation of dramatic mass transport due to 1.5 MeV  $\text{Au}^{2+}$  ion impact on isolated Au nanostructures of an average size  $\approx 7.6$  nm and a height  $\approx 6.9$  nm that are deposited on Si (111) substrate under high flux ( $3.2 \times 10^{10}$  to  $6.3 \times 10^{12}$  ions  $\text{cm}^{-2} \text{s}^{-1}$ ) conditions. The mass transport from nanostructures found to extend up to a distance of about 60 nm into the substrate, much beyond their size. This forward mass transport is compared with the recoil implantation profiles using SRIM simulation. The observed anomalies with theory and simulations are discussed. At a given energy, the incident flux plays a major role in mass transport and its re-distribution. The mass transport is explained on the basis of thermal effects and creation of rapid diffusion paths at nano-scale regime during the course of ion – irradiation. The unusual mass transport is found to be associated with the formation of gold silicide nanoalloys at sub-surfaces. The complexity of the ion – nanostructure interaction process has been discussed with a direct observation of melting (in the form of spherical fragments on the surface) phenomena. The sputtered particles size distribution found to be bi-modal in nature at high flux irradiation conditions. The loss of the material from the gold nanostructures found to be more at high fluxes, showing the effect of wafer temperature on the sputtering phenomena. The transmission electron microscopy, scanning transmission electron microscopy and Rutherford backscattering spectroscopy methods have been used.

**(l) Flux dependent self ion induced sputtering from Au nanostructures:**

[Ref: J. Ghatak et al. J. Phys. D: Applied Physics (2008) (under review)];

The 1.5 MeV self – ion induced sputtering and mass transport from gold nanostructures (deposited on silicon substrate) of an average size  $\approx 7.6 \pm 1.5$  nm

and height  $\approx 6.9 \pm 0.8$  nm has been studied at various fluences ( $0.6 - 10$  ions  $\text{nm}^{-2}$ ) and fluxes ( $3.2 \times 10^{-4} - 6.3 \times 10^{-2}$   $\text{nm}^{-2} \cdot \text{s}^{-1}$ ) and the results are compared with thick and continuous gold film ( $\approx 27.5$  nm thick gold film on silicon). For the case of nanostructures, a reversal of sputtering yield variation has been observed at higher fluences and at higher flux and is attributed to the onset of mass transport into the substrate. The flux dependent wafer temperature increases the sputtering yield from both nanostructured thin films and bulk films. The sputtering and mass transport has been studied using the Rutherford backscattering spectrometry and transmission electron microscopy methods. For the case of nanostructures, a reversal of sputtering yield variation has been observed at higher fluences and at higher flux and is attributed to the onset of mass transport into the substrate. The flux dependent wafer temperature increases the sputtering yield from both nanostructured thin films and bulk films. The sputtering and mass transport has been studied using the Rutherford backscattering spectrometry and transmission electron microscopy methods.

**(m) Enhanced diffusion and segregation from gold nanostructures in amorphous silicon under MeV ion bombardment**

[Ref: J. Ghatak et al Appl. Phys. A. (to be communicated) (2008)]

Mass transport from gold nanostructured thin films into silicon substrate matrix under high flux ion beam bombardment involves non-equilibrium phenomena of formation of defects and with diffusion and segregation governed by various defects paths and dynamic substrate temperatures. Under these conditions, mass transport has been studied in Au thin films of various thicknesses (2, 5.3, 10.9 and 27.5 nm) deposited on Si(111) and followed by irradiation with 1.5 MeV  $\text{Au}^{2+}$  at a flux of  $6.3 \times 10^{12}$  ions  $\text{cm}^{-2} \cdot \text{s}^{-1}$  and at fluencies up to  $1 \times 10^{15}$  ions  $\text{cm}^{-2}$ . Dramatic mass transport associated with gold silicide formation has been observed for the above-mentioned systems at fluence  $\leq 1 \times 10^{14}$  ions  $\text{cm}^{-2}$ . The maximum transported depth at a fluence of  $1 \times 10^{14}$  ions  $\text{cm}^{-2}$  for the cases of 2.0, 5.3, 10.9 and 27.5 nm thick films has been found to be 60, 95, 250 and 13 nm respectively. Interestingly, at higher fluence of  $1 \times 10^{15}$  ions  $\text{cm}^{-2}$ , for a 27.5 nm thick film yielded a distance of 265 nm in the substrate while segregation of gold atoms at the surface has been observed for 2.0 nm thick gold film on silicon substrate. For both the diffusion and the segregation, the nature of the substrate silicon is found to be amorphous in nature and no thermal annealing steps were used unlike many previous studies. The observations have been made using transmission electron microscopy and Rutherford backscattering spectrometry experimental methods. Mass transport is explained on the basis of incident ion beam induced, flux dependent amorphous nature of the substrate, formation of various kind of defects and instantaneous beam induced temperature.

## **(II) Soft matter related:**

### **(a) Pattern growth of Ge films on PtBA polymer substrates:**

[Ref: P. V. Satyam et al., Physica **E27** (2005) 235]

A pattern growth of Ge wires is observed on Poly(tert-butyl acrylate) (PtBA) polymer. PtBA polymer of 30 and 100nm thick has been deposited on silicon substrate using spin coating. Thin films of Ge of various thicknesses ranging from 0.5 to 7.4nm were grown using magnetron sputtering and molecular-beam epitaxy (MBE). RBS has been used to determine effective thickness of Ge films. SEM, AFM and TEM were used to characterize the wire patterns. The wire-like structures were found to be of Ge as detected by energy dispersive X-rays during SEM measurements. TEM measurements show that these Ge wires are single crystalline in nature.

### **(b) Proton Microbeam irradiation effects on PtBA polymer**

[J. Kamila et al, Bull. Mater. Res. **29** (2006) 101]

Proton beam lithography has made possible to make various types of 3D-structures in polymers. Usually PMMA, SU-8, PS polymers have been used as resist materials for lithographic purpose. Microbeam irradiation effects on poly-tert-butyl- acrylate (PtBA) polymer using 2.0 MeV proton microbeam are reported. Preliminary results on pattern formation on PtBA are carried out as a function of fluence. After writing the pattern, a thin layer of Ge is deposited. Distribution of Ge in pristine and ion beam patterned surface of PtBA polymer is studied using the optical and secondary electron microscopy experimental methods.

### **(c) Transmission Electron Microscopy of gold and silica polymer nanocomposites:**

[M. Umananda Bhatta et al., Solid State Symposium 2007 Proceedings] [Full paper to regular journal is under preparation]

Polymer nanocomposite structures play an important role in nanotechnology. In this report, we present low-temperature transmission electron microscopy studies on these systems. Well dispersed TOAB capped gold colloids, CTABr capped gold nanorods and mesoporous silica are prepared by chemical methods. These nanostructures were incorporated in to PS matrix directly as well as via in-situ styrene polymerization. TEM result show that in-situ polymerization yield better dispersion of nanostructures.

**(a) Structural analysis of RF sputtered and spin coated thin films using RBS**  
[Ref: M. Umananda Bhatta et al, Nucl. Instrum. Methods Res. B266 (2008) 1548]

Thin films of gold and chromium on silicon substrates have many technological applications such as contact layers. They are also used as mirrors in synchrotron radiation research. Thin metallic films on Si(100) were used as substrates for Polystyrene (PS) polymer spin-coating for studying the various interesting phenomena such as dynamics in confined layers, and radiation damage research. To obtain continuous thin metallic films (a few nm's thick), a Cr layer was first deposited as an adhesion layer on the silicon substrate. Also, when many sputter targets are used in general purpose sputter coating units, it is necessary to determine the actual thickness and compositions of the films besides sharpness at the surface and interfaces. We will present Rutherford backscattering analysis (RBS) of Si/Cr/SiO<sub>2</sub>/Si, Si/Au/Cr/SiO<sub>2</sub>/Si, and Polystyrene (PS) polymer coated on some of these bi- or tri- layer structures. The X-ray reflectometry and transmission electron microscopy studies were carried out to complement the RBS measurements. The various thin films were used for creating extra photo-electrons to enable the study of mechanism of photon or ion induced radiation damage (in case of polymers on these thin films). Also, we are using the thin films in understanding the ion – induced modification in confined nano-thin films

**(e) Ion and X-ray irradiation induced damage in polymer (PS) thin films**  
[M. Umananda Bhatta et al, Thin Solid Films (2008) (to be communicated)]

Radiation damage in materials can be used to modify the properties. Here, we report the use of X-ray reflectivity to study ion irradiation and x-ray irradiation damage in thin films of polystyrene polymeric (PS). The basic mechanism for the cause of radiation damage is studied by varying the number of electrons inside the polymeric films. The polymer films of various molecular weights are grown on a silicon surface with a chromium layer as a sandwiched metallic layer that produces photoelectrons (with x-rays) or ionized electrons (with energetic ion beams). For PS, owing to its structure and a tendency to cross link upon irradiation at room temperature (much below its glass transition temperature) earlier studies have shown a decrease in interfacial roughness and a slight increase in thickness. Similar trend is observed in the presence of a thin (about 25 Å) layer of chromium film. But when the chromium layer thickness was increased by about 20 times interesting reversal effect was observed for x-ray radiation damage. Thickness of the polystyrene film decreased and interfacial roughness also increased.

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