Chapter 7

Summary and Conclusions

Driven by tremendous technological applications in microelectronics, magnetic and optoelectronic devices, the growth of epitaxial films on single crystal semiconductor surfaces has been the subject of extensive experimental and theoretical studies over a few decades. Epitaxial metal films on semiconductors can provide sharp interfaces, thermally stable Schottky barrier formation, high electron mobility and long electromigration lifetime.

The thesis work mainly involve the growth of Au, Ag and Pb layers on Si surfaces, growth of thermally or ion-irradiation induced self-assembled structures, epitaxial or otherwise, in these systems and characterization using Rutherford backscattering spectrometry/ channeling, ion induced x-ray emission, Auger electron spectrometry, optical microscopy and atomic force microscopy. A major portion of the thesis work involve the development of two beam lines, namely ion micro-beam and surface physics beam line, and the associated experimental facilities with the 3MV tandem Pelletron accelerator at our laboratory. These facilities are unique and first of their kinds in the country.

Thin Au films deposited on Br-passivated Si surfaces ((111),(110),(100)) and annealed around 363 °C (Au-Si eutectic temperature) have produced epitaxial gold-silicide islands in a self-assembled growth process with various shapes following the symmetry of the underlying substrates.
Earlier observations have shown that on a Si(111) surface, triangular silicide islands grow up to a certain critical size, depending on the thickness of the initial deposited uniform Au layer, and then transform into a trapezoidal shape—a phenomenon called shape transition. Shape transition is one of the strain relieving mechanisms in the heteroepitaxial systems. Micro-RBS results show the composition of the gold silicide to be $Au_4Si$. The islands are found to grow in layer-plus-island growth mode. By varying the annealing temperature over a small temperature range around the eutectic temperature, we obtained other shapes of islands expected for growth on a substrate of three-fold symmetry—prominent among them are hexagonal islands. AFM micrographs showed the hexagonal islands with well-defined facets. A tentative explanation of the shapes was given following the results of existing kinetic Monte Carlo (KMC) simulations.

Earlier we have observed the growth of parallel, wire-like epitaxial gold silicide islands on Si(110) surfaces. These islands are quite long with an aspect ratio as large as 200:1 and their orientation reflects the two-fold symmetry of the Si(110) substrate. Anisotropic strain has been identified to be the main cause of the formation of long wire-like islands.

Though passivation of Si(100) surfaces with bromine is very short lived (less than an hour), we were able to grow epitaxial square and rectangular shaped gold-silicide islands on this surface. The observation of square shaped islands are due to the four-fold symmetry of the underlying Si(100) substrate. The transition to long rectangular shaped islands is predicted from the theory of shape transition. The rectangular islands are oriented along mutually perpendicular directions, allowed by the four-fold symmetry of the Si(100) surface.

We believe it would be possible to grow quantum dots and wires by this non-UHV method with proper optimization of growth parameters. Scientists working on atomically clean surfaces under UHV condition may look down upon deposition under HV conditions on chemically bromine-passivated substrates as "dirty" systems. However, the fact remains that this "dirty" system has shown results comparable to "clean" systems. Additionally, the phenomenon of shape transition, predicted for the "clean" system has been first observed for this "dirty" system. Epitaxial growth of
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gold silicide on bromine-passivated Si substrates has been convincingly demonstrated.

A brief description of the development of an ion micro-beam facility at IOP, Bhubaneswar along with the resolution scans has been presented. A spatial resolution of \( \sim 2.5 \, \mu \text{m} \) with a beam current of 80 pA has been achieved using 2 MeV H\(^+\) beam. The major limiting factor of the beam resolution is the negative ion source and tandem accelerator we use. However, this beam resolution is comparable to the performances of other facilities around the world, using a similar tandem accelerator. As one application of this facility, we have analyzed self-assembled epitaxial gold-silicide islands, observed in the Au-Si systems. We have used our microprobe facility for the establishment of mass transport process leading to micro-structure formation in the ion-solid interaction.

We have also implemented a program for pattern scanning with the ion microbeam. With the developments of proper etching techniques, patterned microstructure formation on various metal and semiconductor surfaces can be carried out. The ion microprobe facility has evolved as a characterization tool with a capability of providing three-dimensional concentration profiling of elements in solids.

We have analyzed microstructure formed on epitaxial Ag layers on Si(111) surfaces in (2-12) MeV Si ion irradiation. Although in a metal like Ag with a weak electron-phonon coupling, electron energy loss (\( S_e \)) induced modifications are not expected even at relatively large values of \( S_e \), we have observed \( S_e \)-induced mass transport and island formation on thin grainy epitaxial Ag layers on Si substrates over a moderate range of electronic energy loss. The mass transport apparently gives rise to a triplet structure associated with an island—the island, a Ag-depleted region around the island and a wave packet structure. We believe, the grainness, the interface with the substrate and the proximity of the thin Ag layer to a different material (substrate) are all responsible for the observed effects. More extensive studies are needed to explore the role of these parameters. In the present study, ion microprobe measurements on a few islands, have given the vital clue about the mass transport, confirming that at least some of the islands seen in optical microscopy and AFM are really solid islands and not hollow blisters. In order to establish the total amount of mass transfer, it is necessary to know if all the islands are solid. Whether a majority of islands are solid...
can be determined from conventional RBS measurements with a He$^+$ beam. However, this study was not possible in the present work. Mass transport and island formation appears to be a strain-relieving mechanism for the strained Ag layer.

A brief description of the development of the surface physics beam line with associated experimental facility and some results have been presented. Connection of the UHV experimental facility with one of the beamlines of the tandem accelerator has made the various surface and interface characterization capabilities much more versatile. As a demonstrative case, we have reported the growth of Pb on clean Si(111) surface. Rutherford backscattering spectroscopy and channeling results have provided the evidence of Pb-induced recrystallization of a disordered Si(111) surface. Growth of hexagonal shaped (unequal sides) islands and small grains were observed with AFM on 300 °C-annealed Pb films on Si(111) surfaces. The development of this facility has raised the possibility of studying atomically clean bare surfaces of single crystals, which show interesting reconstructions and relaxations, and growth of metallic epilayers on them. This is the only facility of its kind in India, combining standard surface science techniques with Rutherford backscattering spectrometry and channeling techniques under ultra high vacuum environment.