Electrical Contacts to GaAs for Optoelectronic Applications

Rakesh Sohal

Guided by

Dr.Chacko Jacob

Materials Science Centre
IIT, Kharagpur

Why we need Metal Contacts

1. Provide ohmic contacts to semiconductor devices to allow electrons and holes to enter and leave the semiconductor with little resistance.

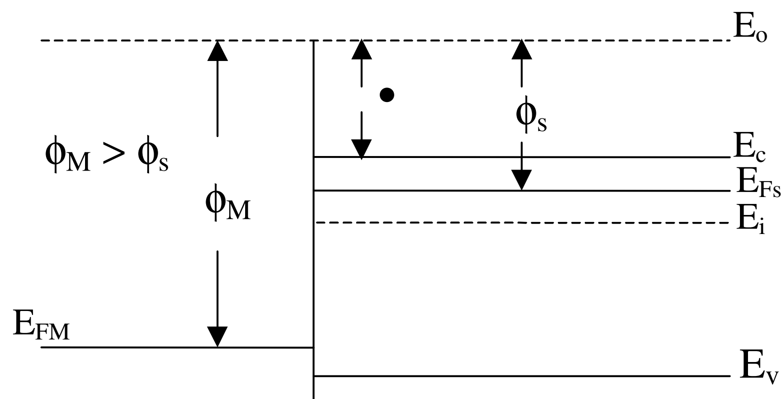
2. Provide rectifying junctions as Schottky barriers to semiconductors.

Requirements for Ohmic Contacts

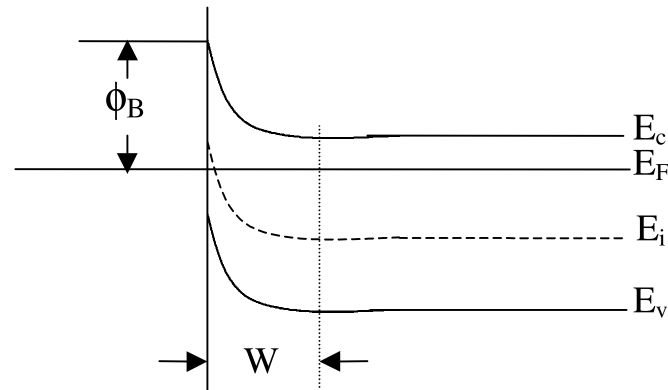
1. Low contact resistance.
2. Thermal stability.
3. Smooth surface, strong adhesion,shallow horizontal and vertical diffusion depth.
4. low metal sheet resistance.

Metal-Semiconductor Junctions

When two materials are joined, electrons will flow from the material with a smaller work function towards that with the larger work function to establish equilibrium or E_F= Constant.



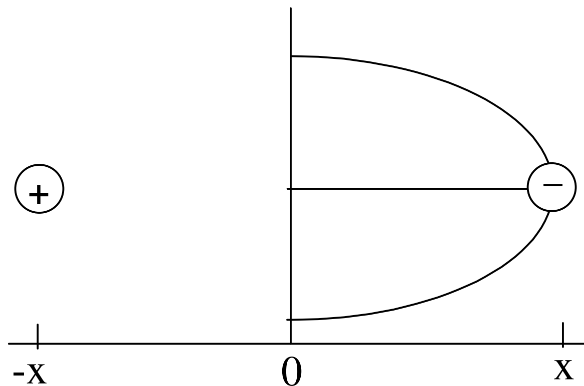
At the instant of contact formation

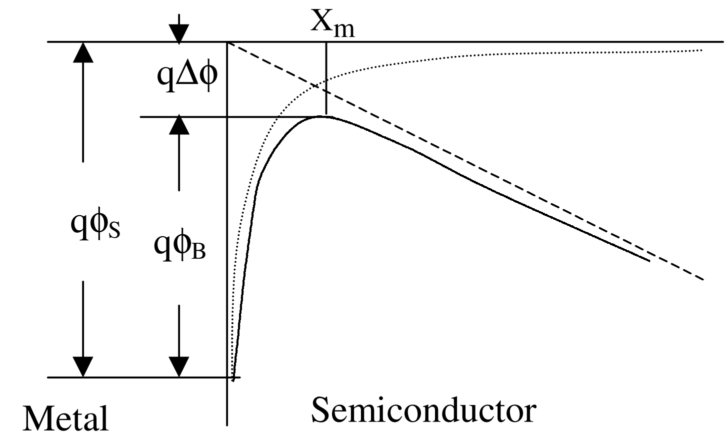


In Equilibrium

Barrier Height Modifications

Image Force Lowering:

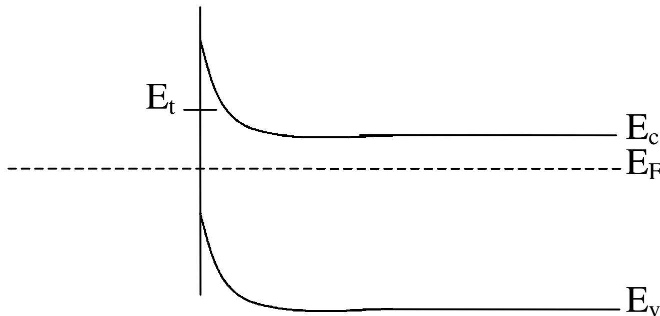




$$E(x) = -q\phi_s - \frac{q^2}{16\pi\kappa\varepsilon_O x^2}$$

Barrier Height Modifications (contd.)

Surface States:



Dangling bonds at the surface create trap levels at the interface.

If the density of traps ast E_t is large $\Rightarrow$ E_f is pinned near E_t

The built-in potential is no more dependent on materials properties

Barrier Height to N & P- type semiconductors will be:

$$\phi_{Bn}=2/3E_g \quad \text{and} \quad \phi_{Bp}=1/3E_g$$

Almost independent of ϕ_M **due to Fermi level pinning at surface.**

Current flow mechanisms:

- ***Thermionic emission***

a. Dominant in moderately doped semiconductors
b. Depletion layer width is large few carriers will transfer over the potential barrier

- ***Thermionic-field emission***

a. Applicable for intermediate doped semiconductors
b. Barrier becomes thin
c. Thermally excited carriers can tunnel through near the top of the barrier
d. This transfer of carrier is temperature dependent

Current flow mechanisms (contd.)

- ***Field emission tunneling***

  a. Effective in heavily doped semiconductors

  b. Barrier becomes so thin –significant number of carriers can tunnel through even at base of the barrier

Surface Cleaning Of Silicon and GaAs

Si (100) samples (n-type) were cleaned by TCE (trichloroethylene), acetone HF (5%).

GaAs samples were first cleaned in hot TCE then in hot acetone.

Alloy preparation for ITO

Indium-tin alloy of three different compositions, In:Sn (90:5), In:Sn (93:7) and In:Sn (95:10), (tin weight percent varying) were prepared by melt mixing in open environment.

Evaporation of metals

Deposition parameters for Au, Au-Ge and In-Sn alloy

Metal or Alloy deposited	Base pressure (Torr)	Deposition pressure (Torr)	Time (min.)
Au	3×10^{-6}	3.5×10^{-6}	1.5
Au-Ge	3×10^{-6}	5×10^{-6}	1.5
In:Sn (90:10)	1.5×10^{-6}	2.5×10^{-6}	2.0
In:Sn (97:3)	1.5×10^{-6}	2.5×10^{-6}	2.0
In:Sn (95:5)	1.5×10^{-6}	2.5×10^{-6}	2.0

Deposition parameters for e-beam evaporation:

Base pressure ~ 1.5×10^{-6}Torr, Time of evaporation = 3min.

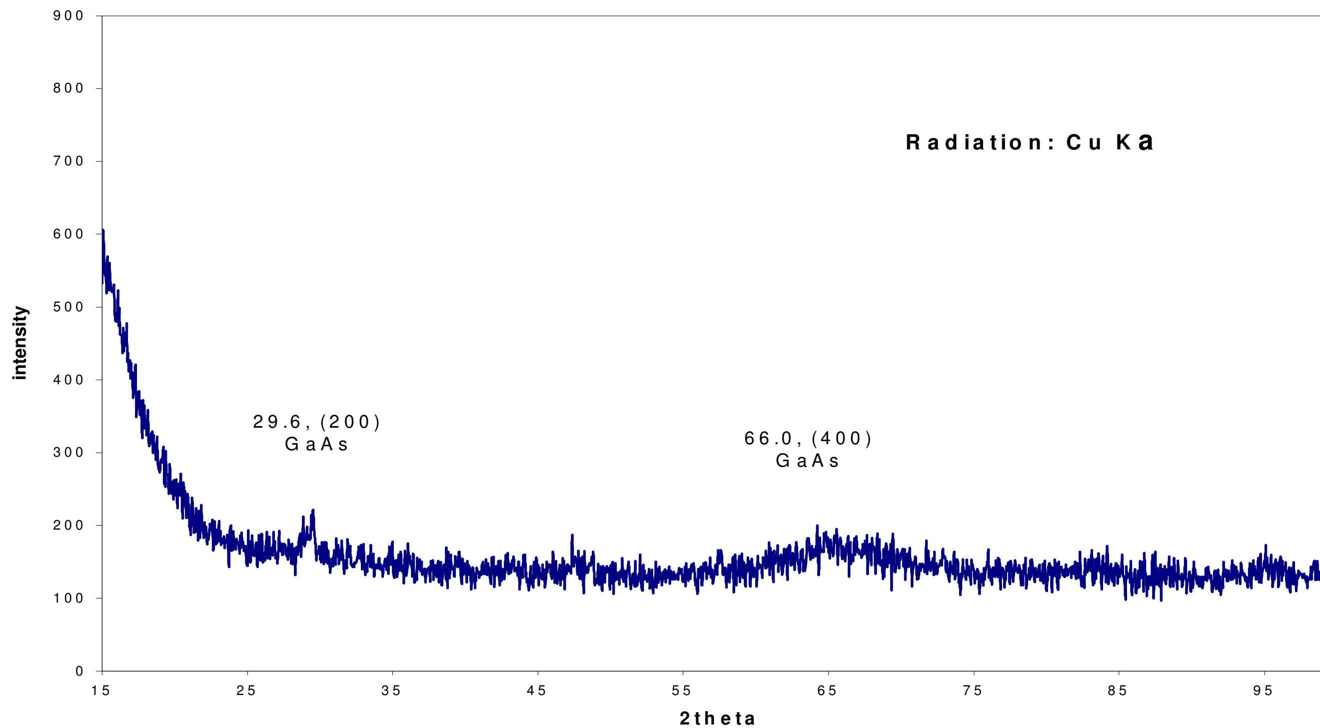
Annealing and Oxidation

Annealing of Au and Au-Ge contacts on Si and GaAs was done in inert atmosphere at 350°C for half an hour.

Oxidation was done for about one and half hour at about 140ºC initially and then at about 370ºC for 2 hours.

Results and discussion

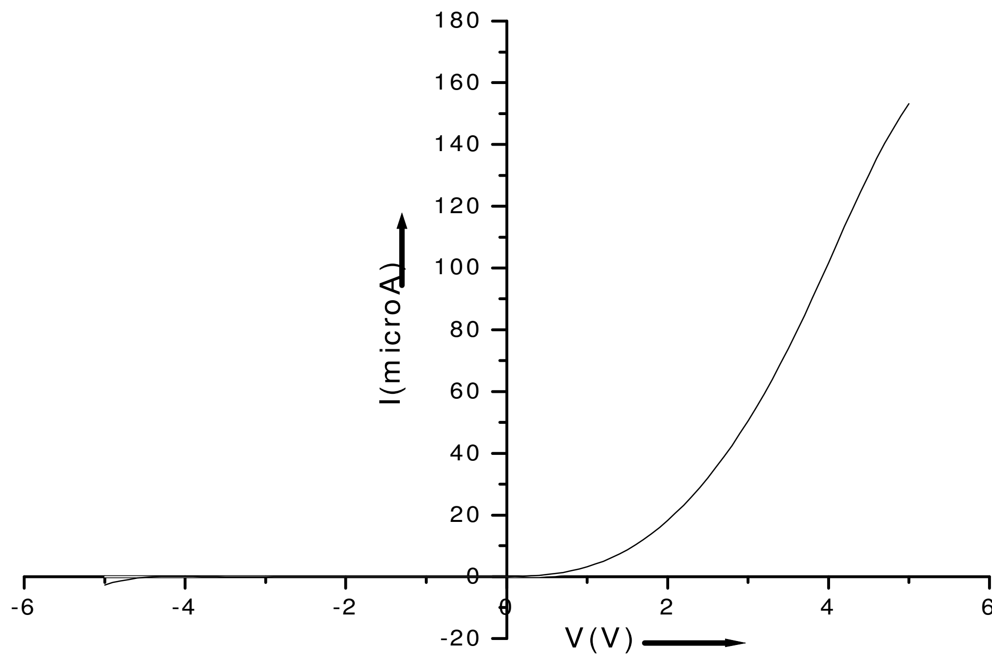
XRD of GaAs Sample:



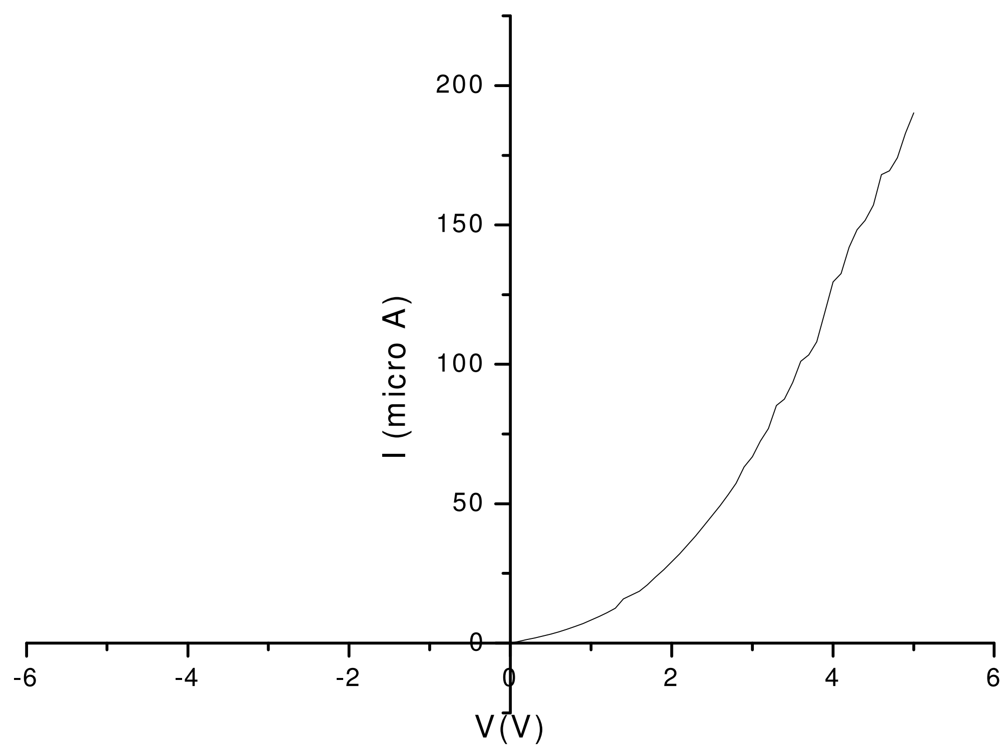
Results and discussion (contd.)

Gold and Gold-Germanium Contacts

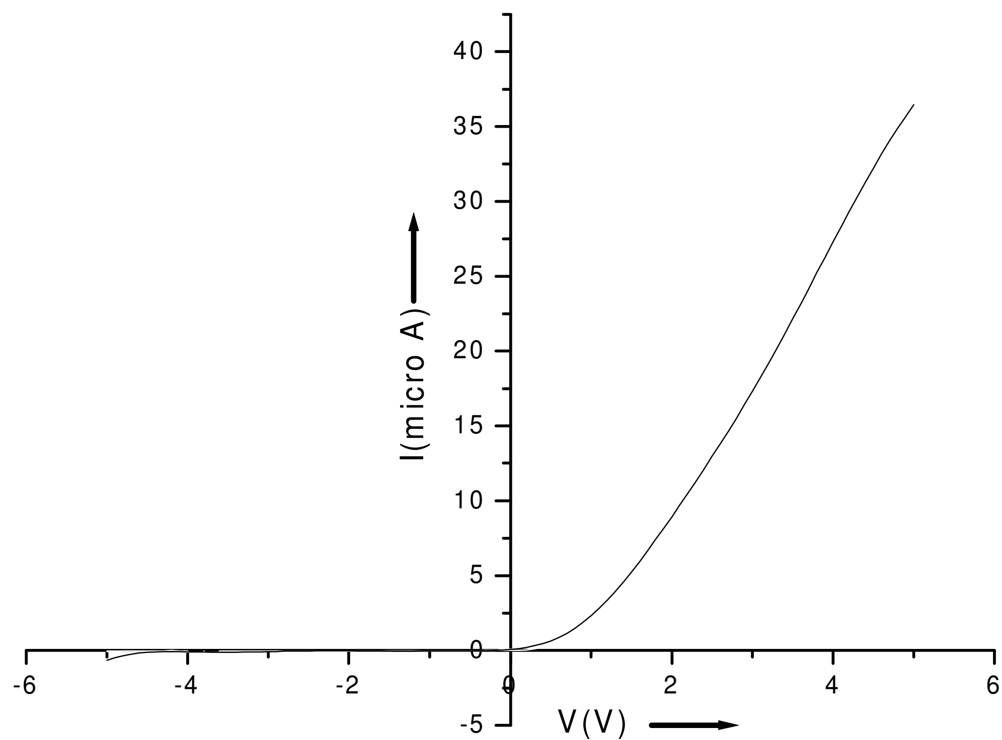
I-V Measurements (Au contact to Silicon as deposted)



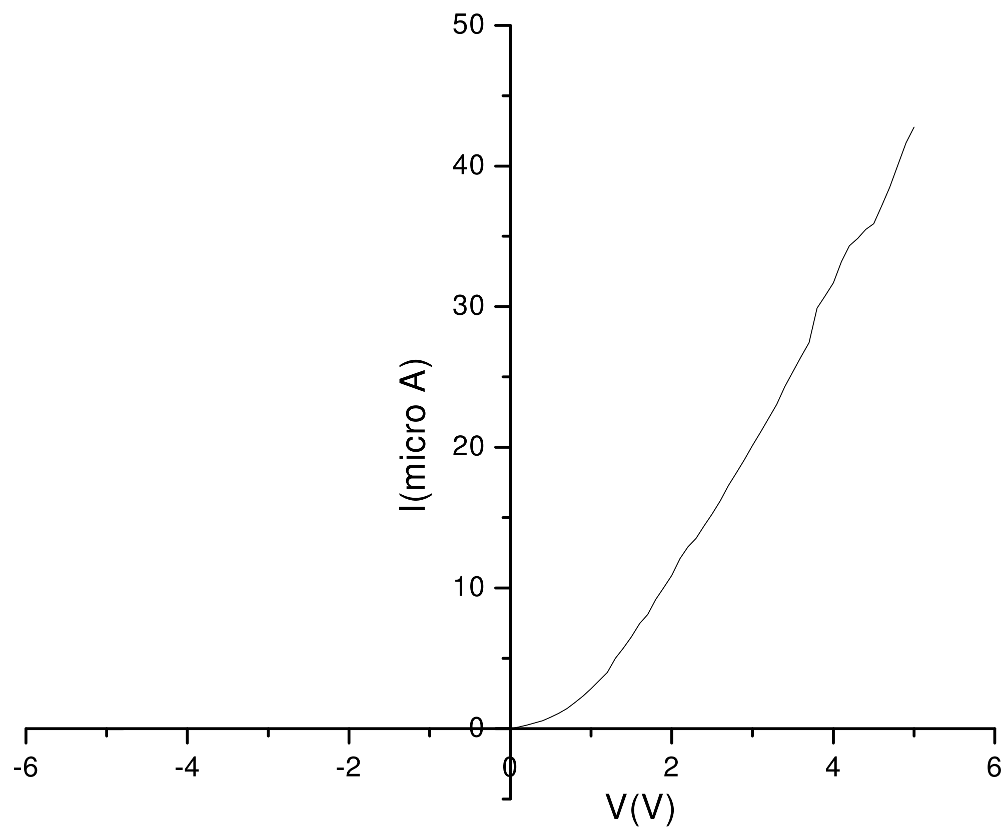
I-V Characteristics of Au/Si after annealing



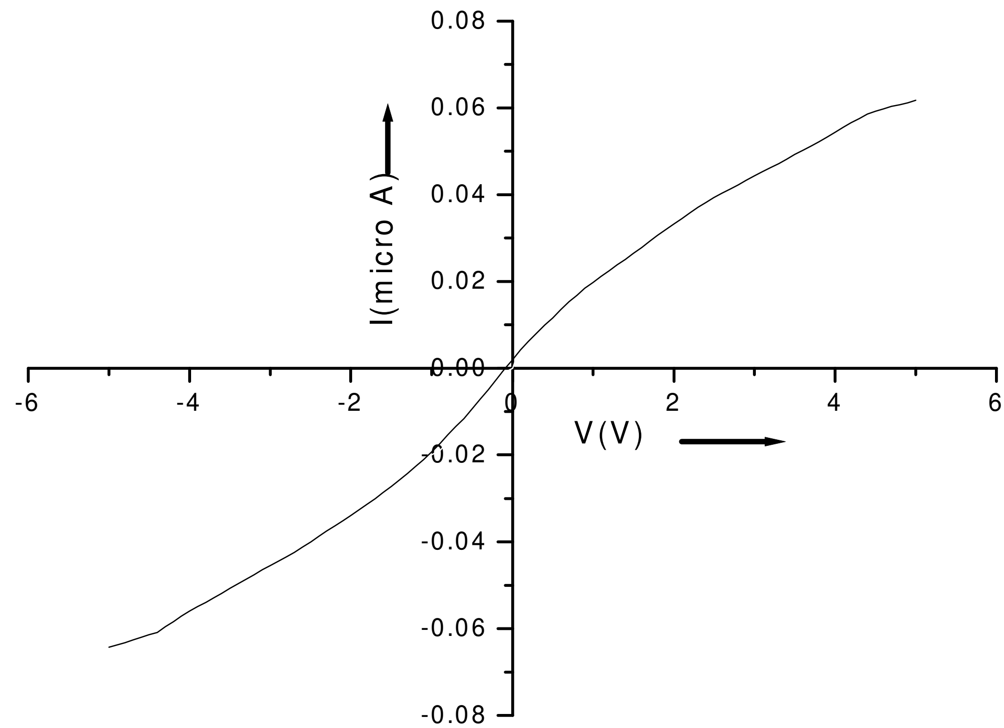
I-V Characteristics of Au-Ge/Si as deposited



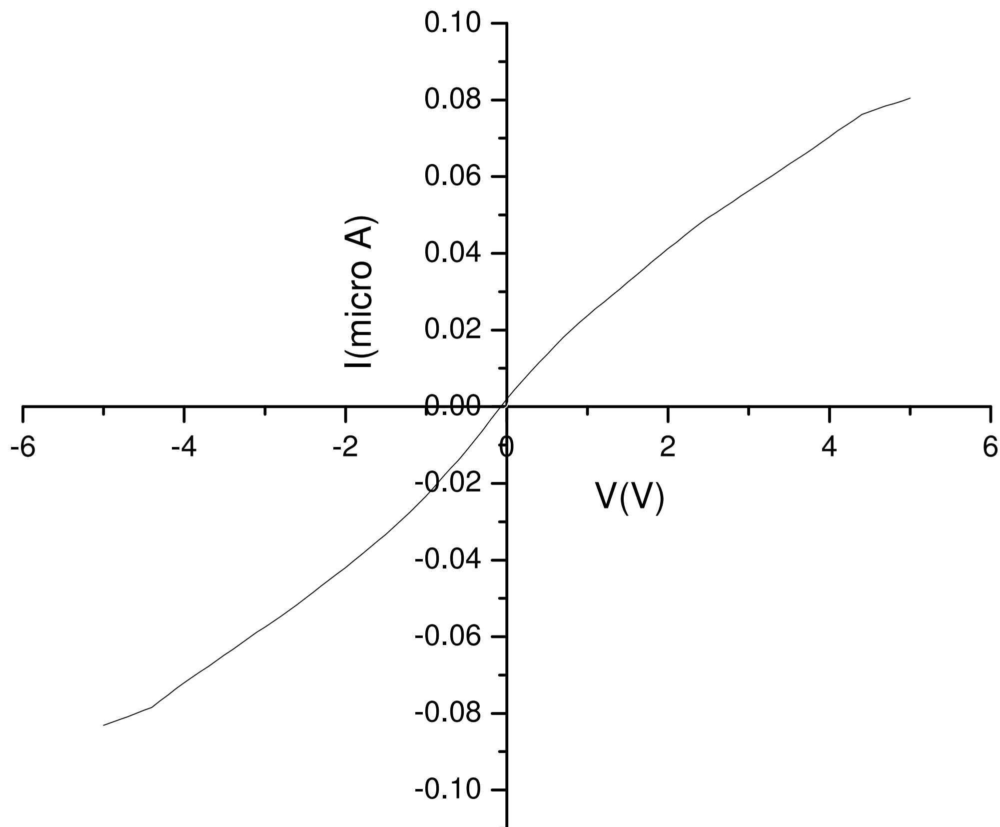
I-V Characteristics of Au-Ge/Si after annealing



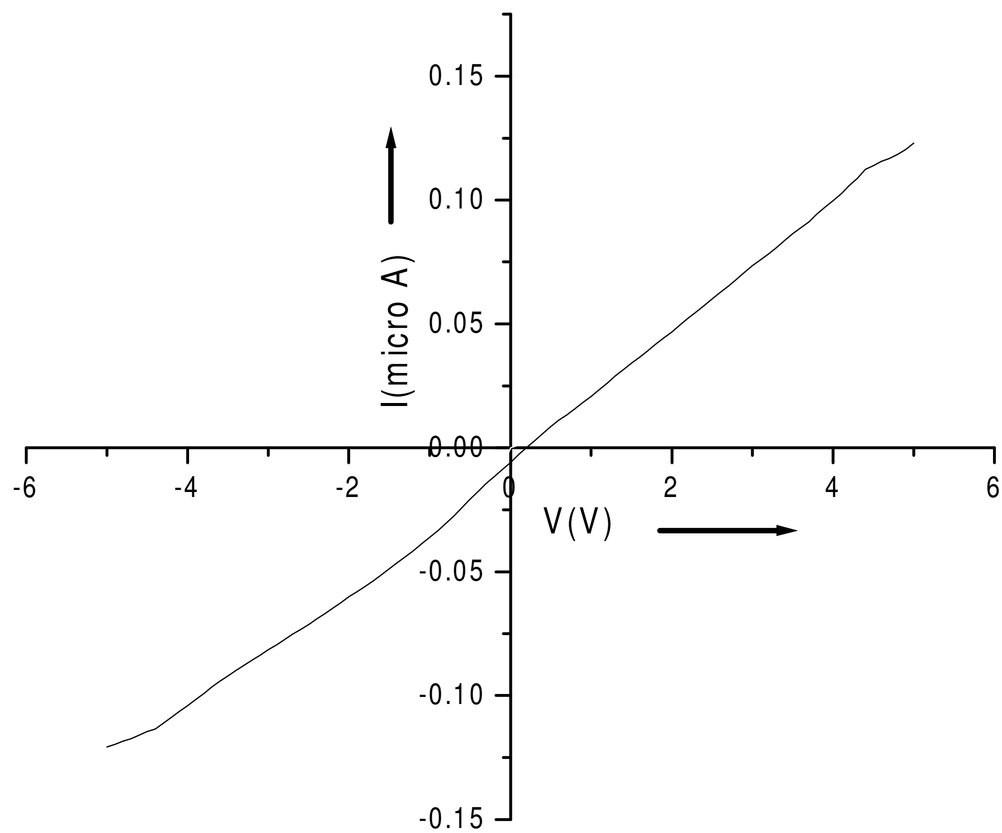
I-V Characteristics of Au/GaAs as deposited



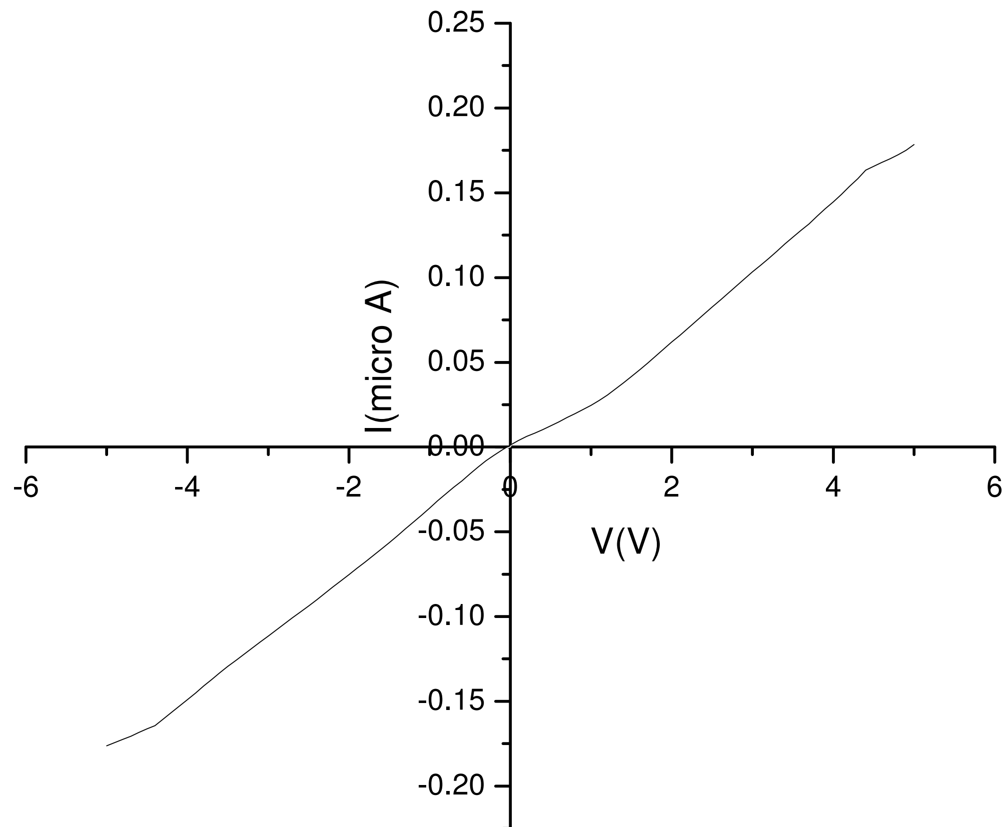
I-V Characteristics of Au/GaAs after annealing



I-V Characteristics of Au-Ge/GaAs as deposited

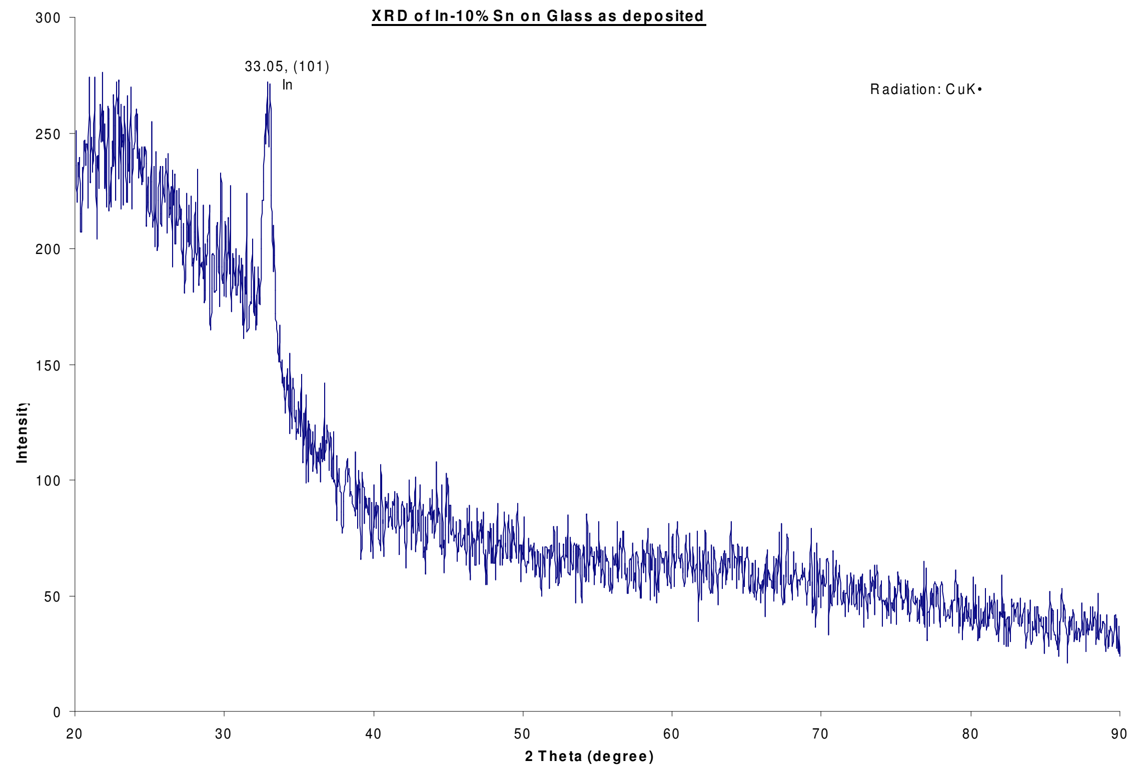


I-V Characteristics of Au-Ge/GaAs after annealing

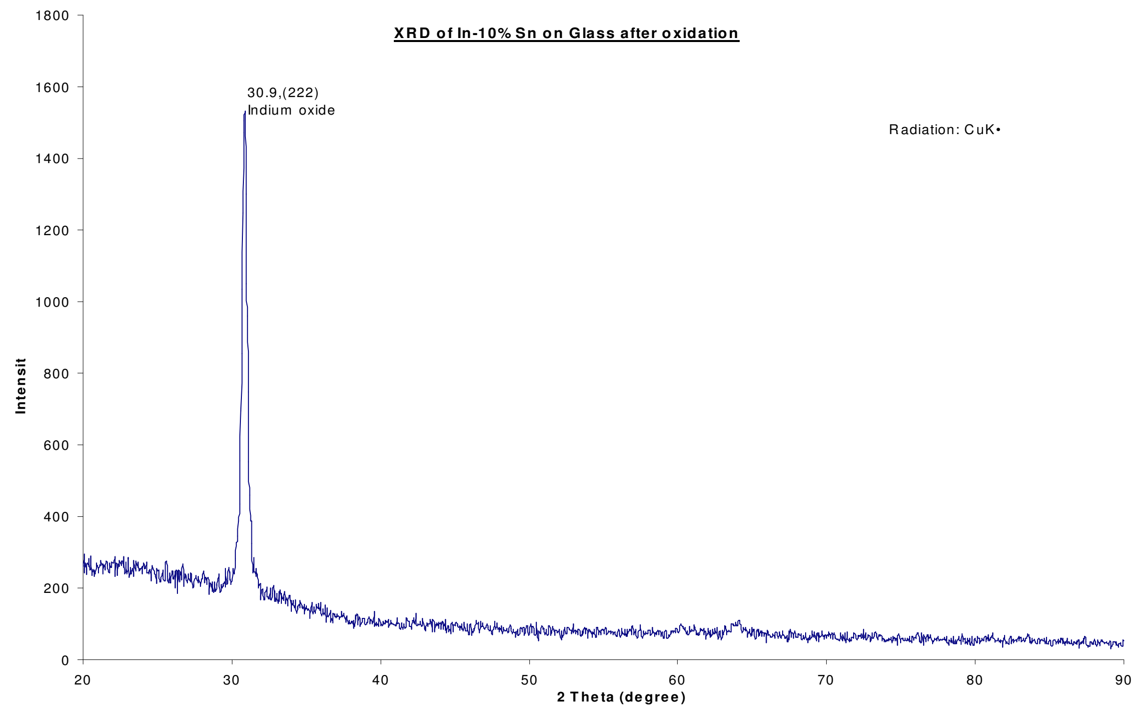


Indium Tin and ITO Contacts

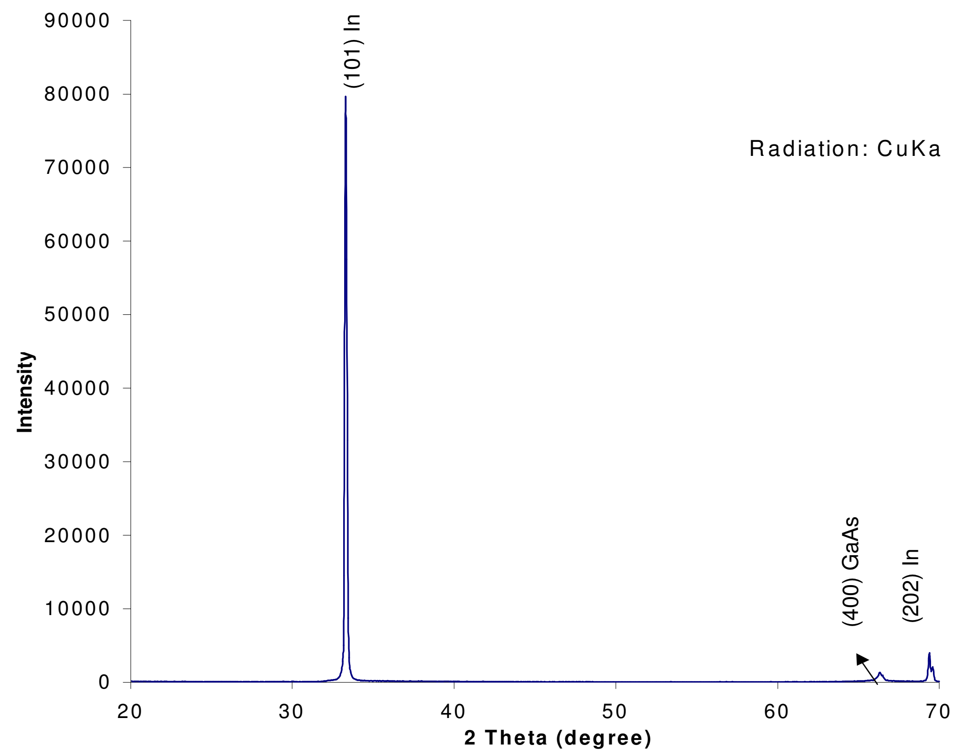
X-Ray Diffraction



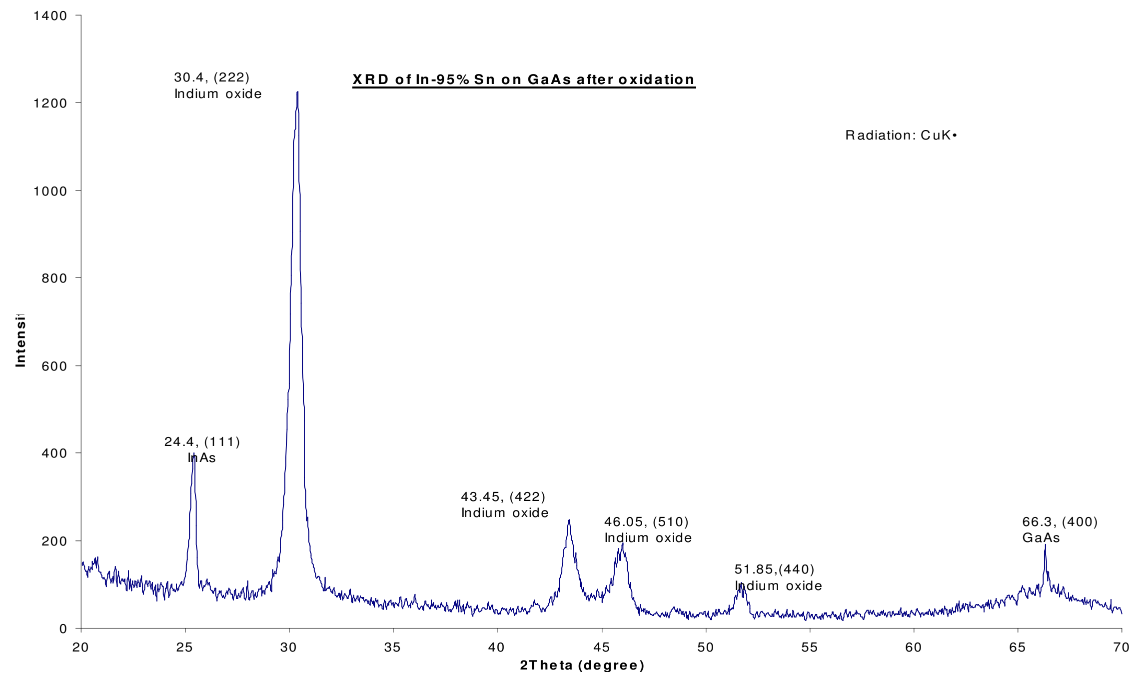
XRD of In-10%Sn on Glass as deposited



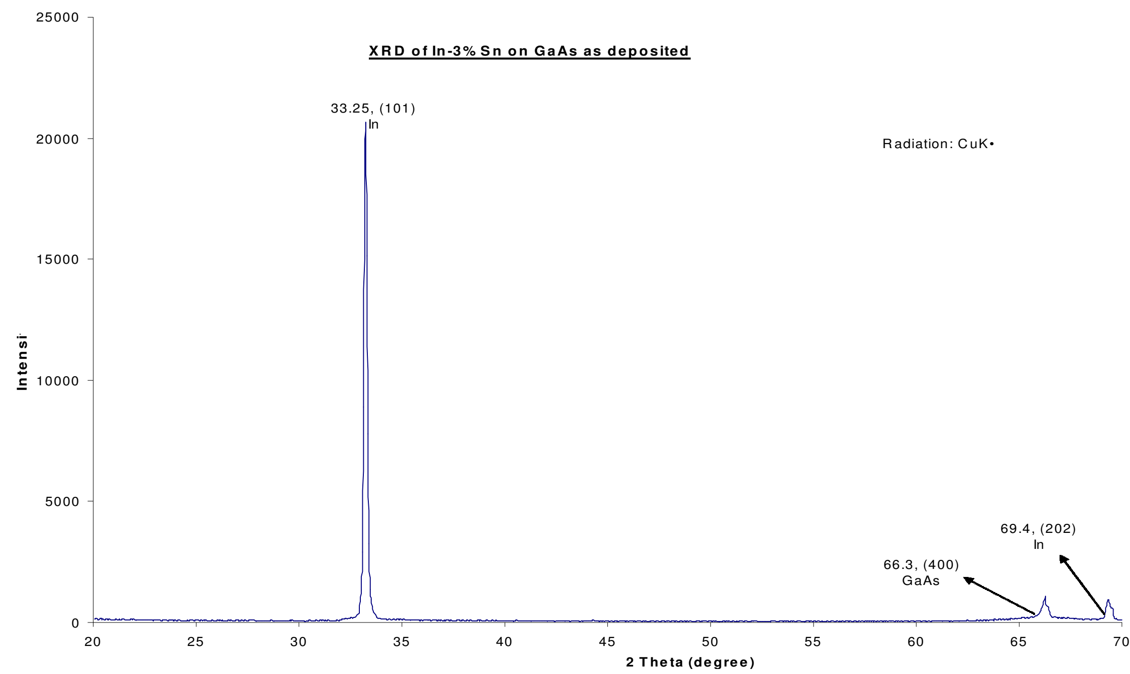
XRD of In-10%Sn on Glass after oxidation



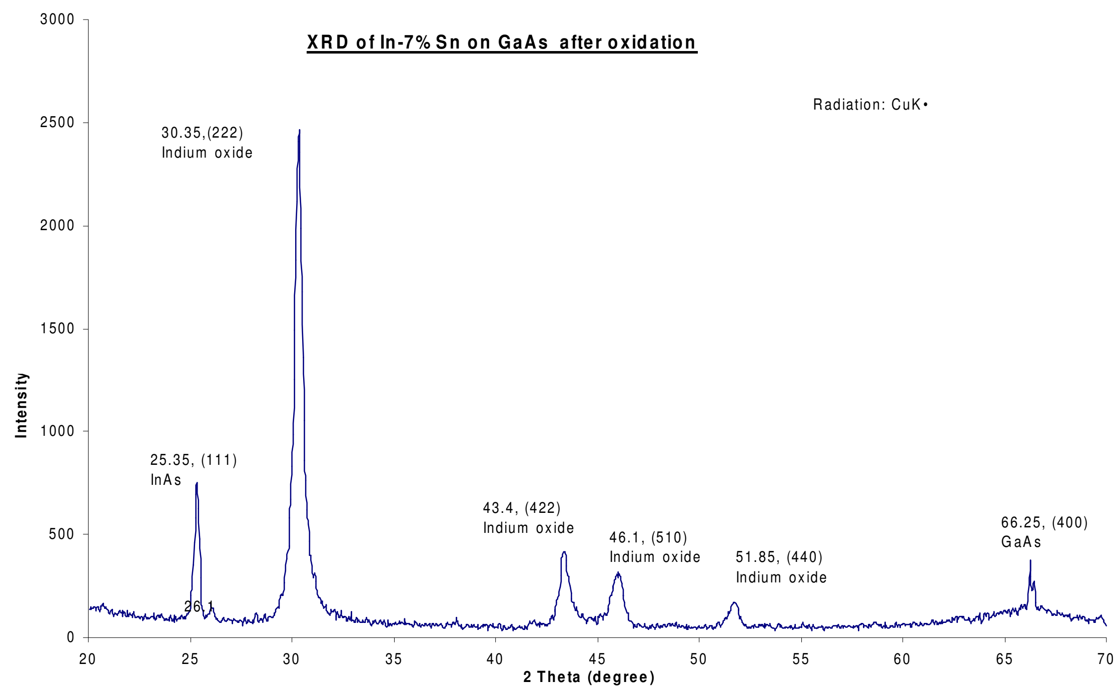
XRD of In-5%Sn/GaAs as deposited



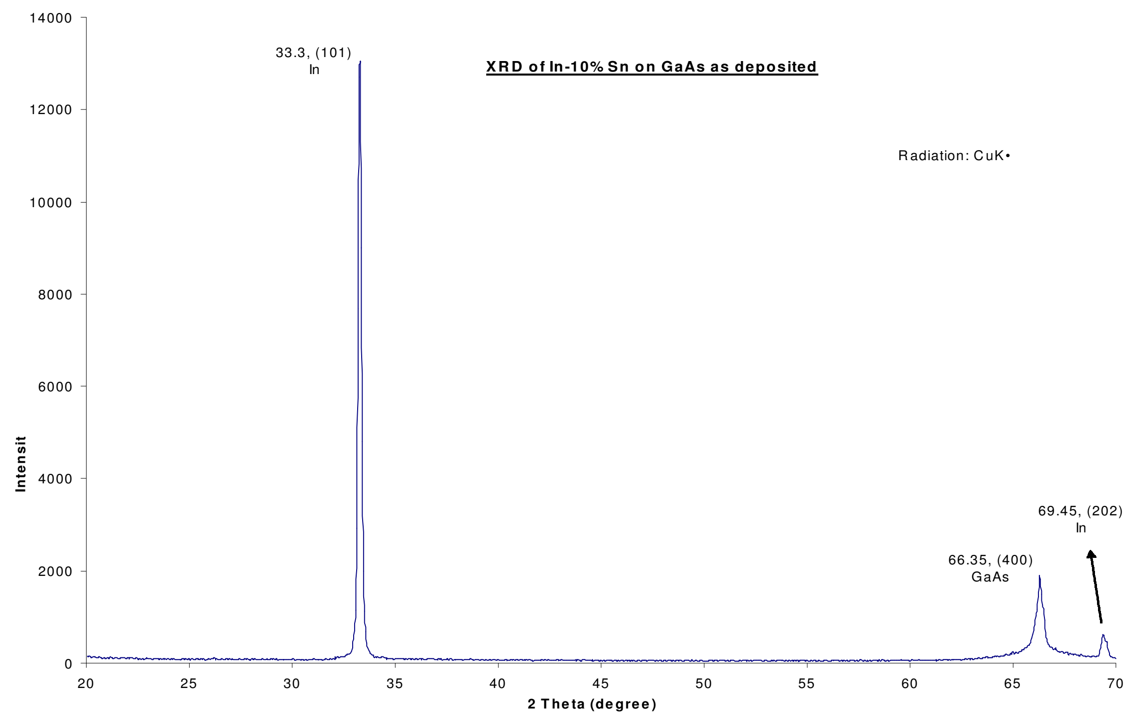
XRD of In-Sn(95:5)/GaAs after oxidation



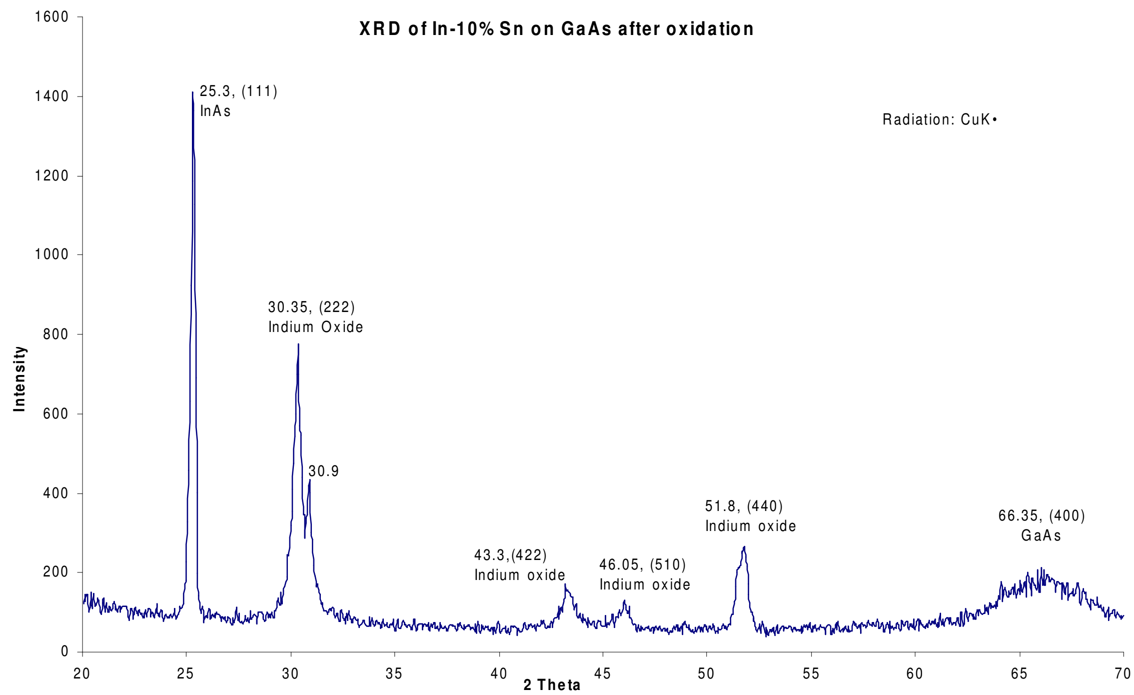
XRD of In-Sn(93:7)/GaAs as deposited



XRD of In-Sn(93:7)/GaAs after oxidation

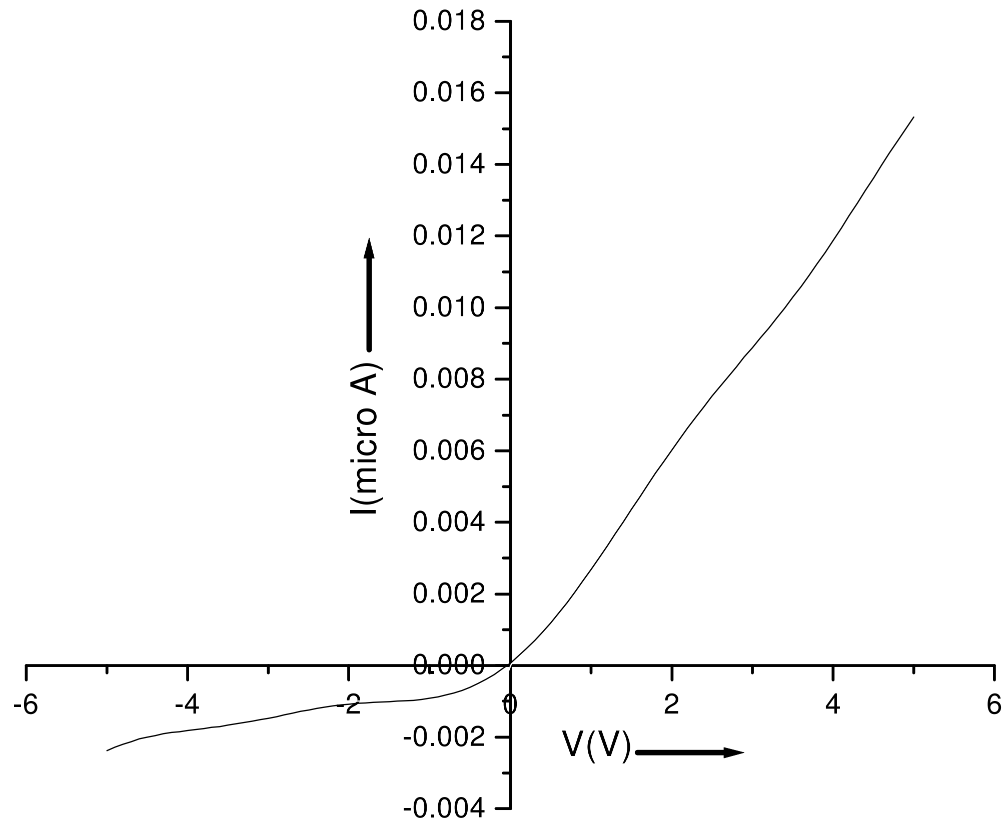


XRD of In-Sn(90:10) as deposited

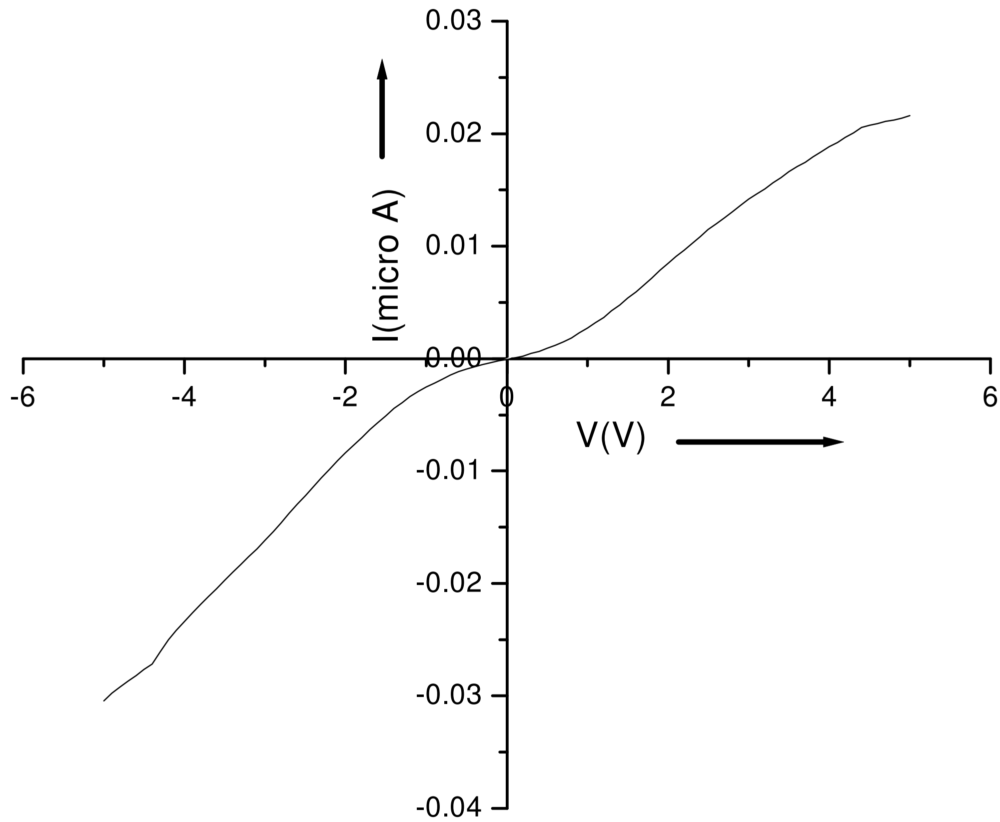


XRD of In-Sn(90:10) after oxidation

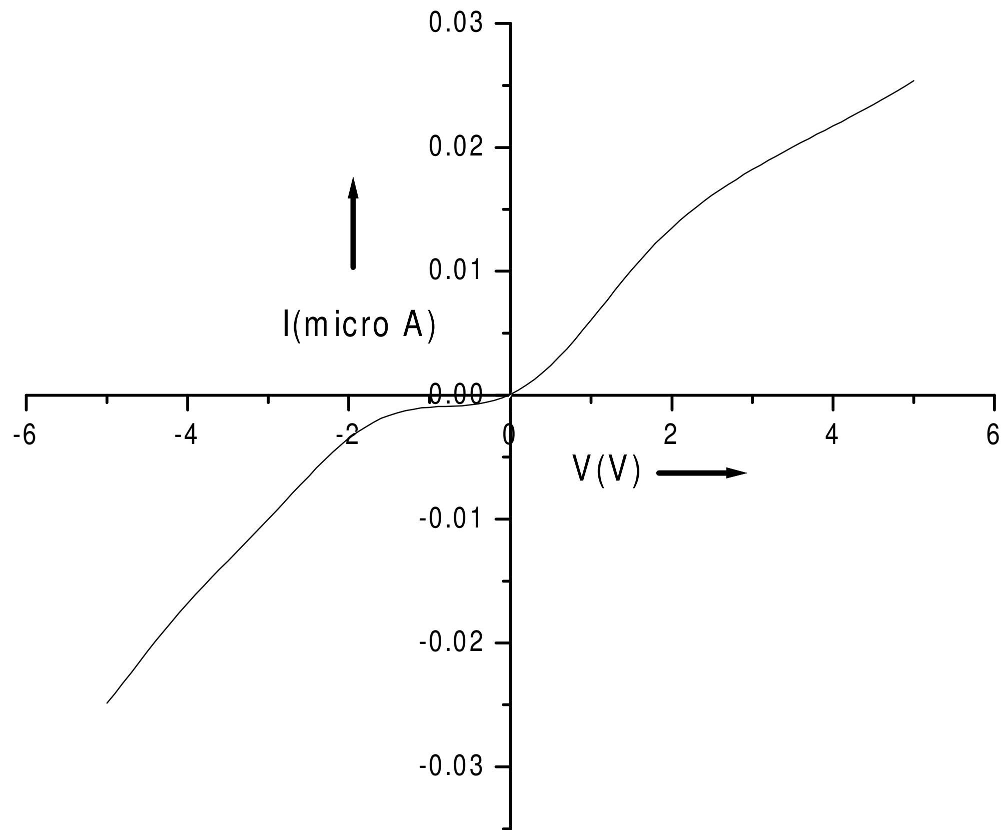
I-V measurements of In-Sn Contacts



I-V measurements on In-5%Sn on GaAs



I-V measurements on In-7%Sn on GaAs contact

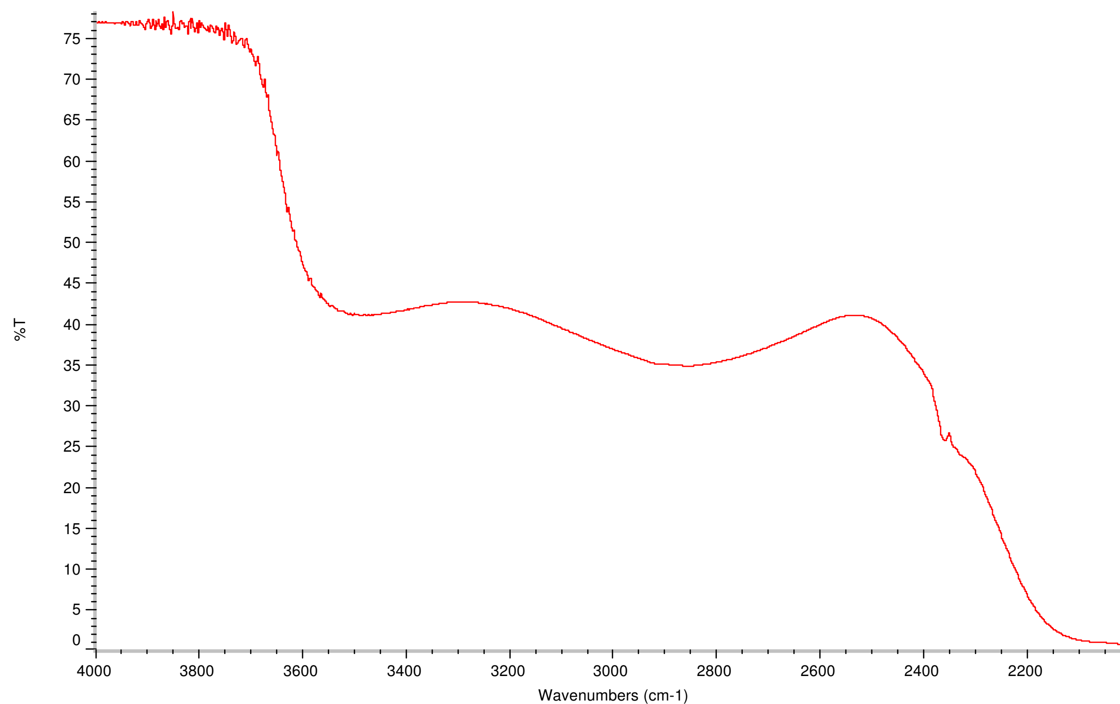


I-V measurements on In-10%Sn on GaAs contact

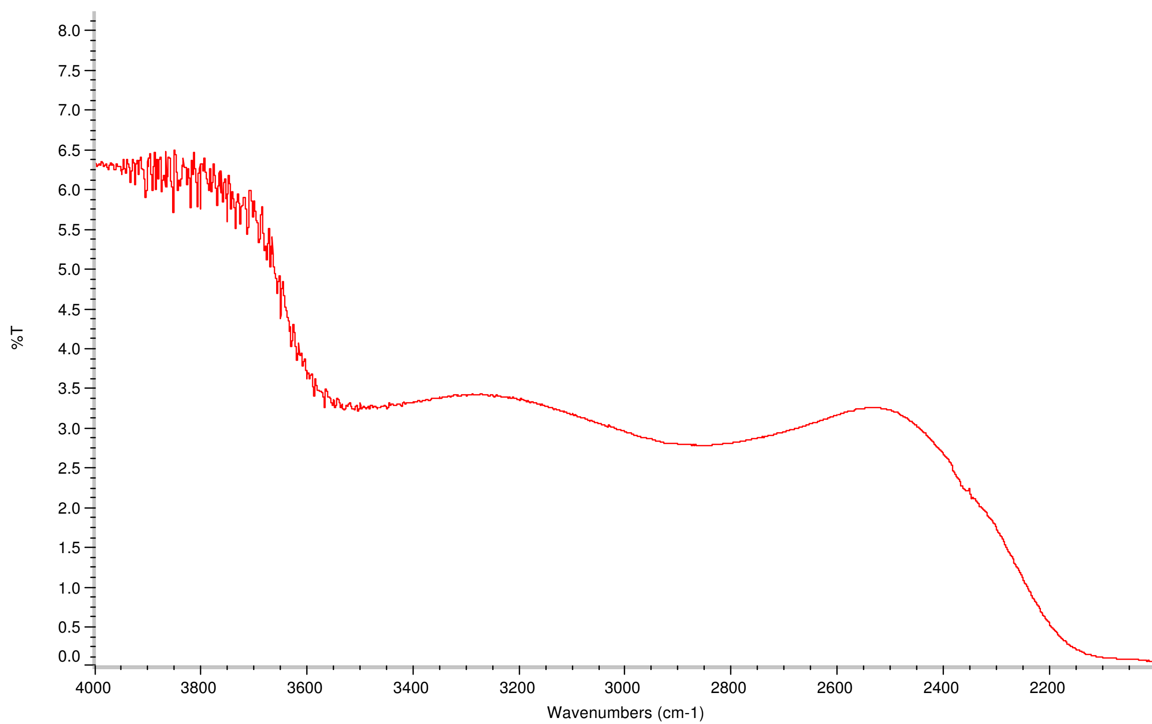
FTIR Measurements

Variation of transmittance of In-Sn after oxidation

Sn composition in In-Sn layer %	Transmittance (%)	
	Before oxidation	After oxidation
5	8	59
7	16	91
10	78	95

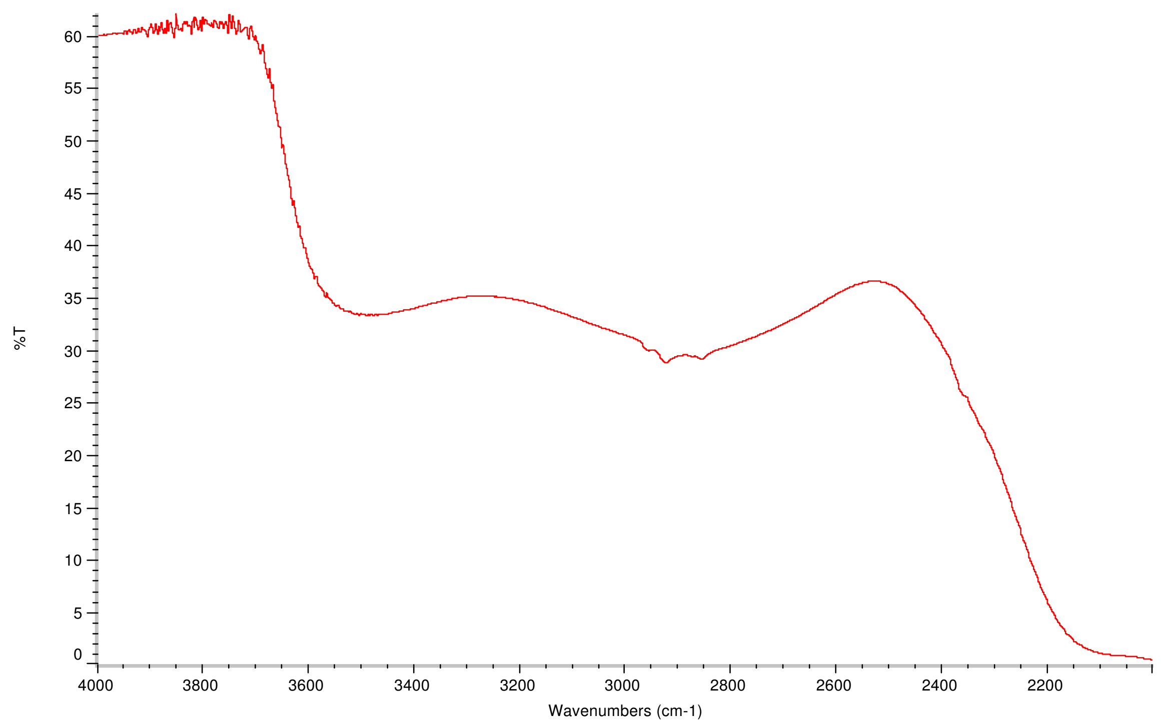


FTIR of bare glass as deposited

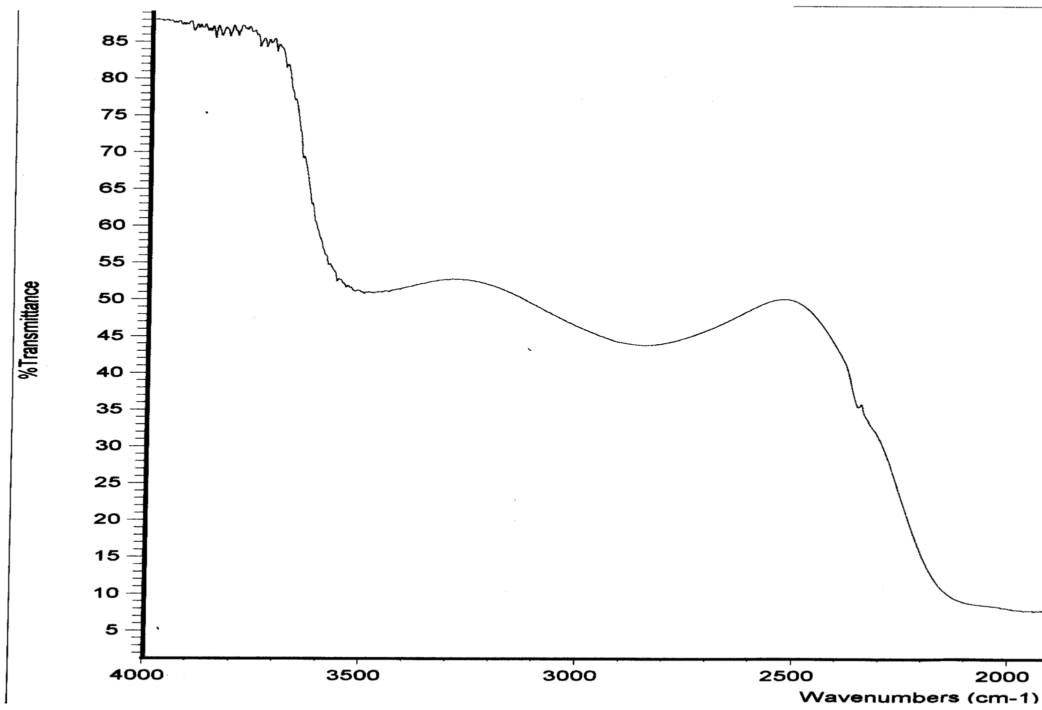


FTIR of In-5%Sn as deposited

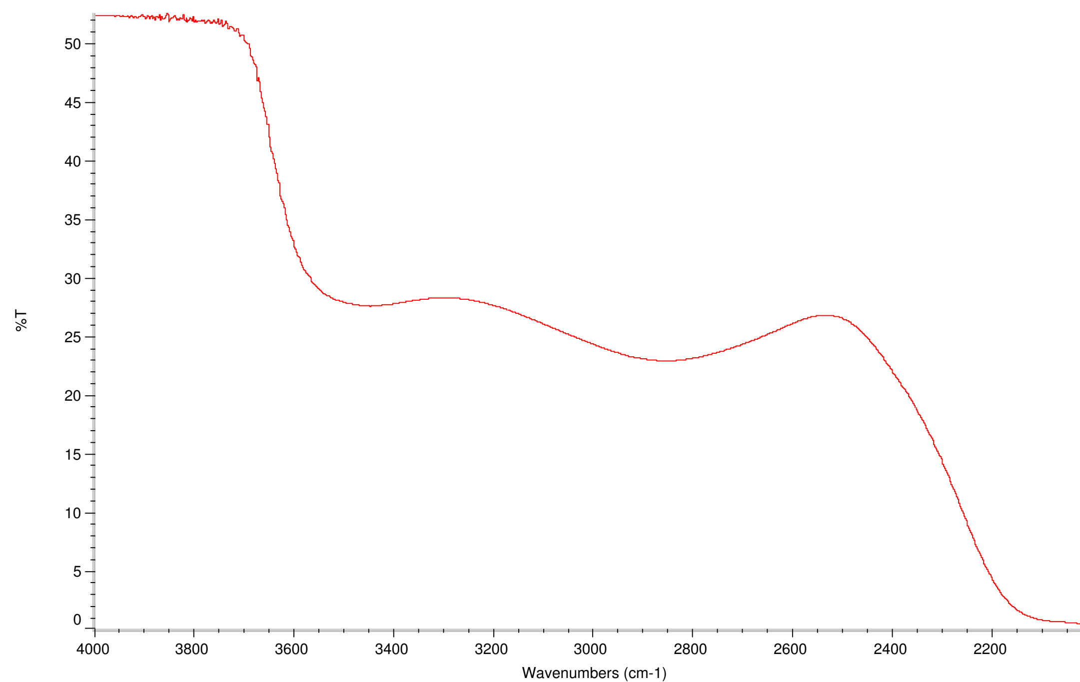
FTIR of In-7%Sn as deposited.



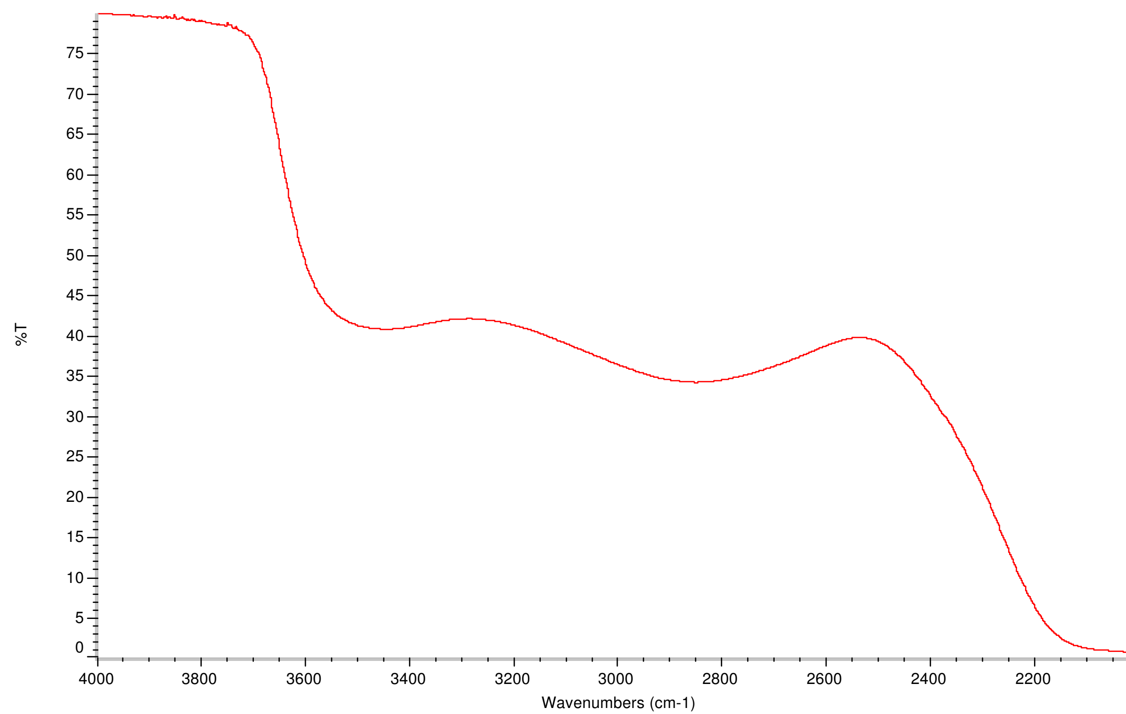
FTIR of In-10%Sn as deposited



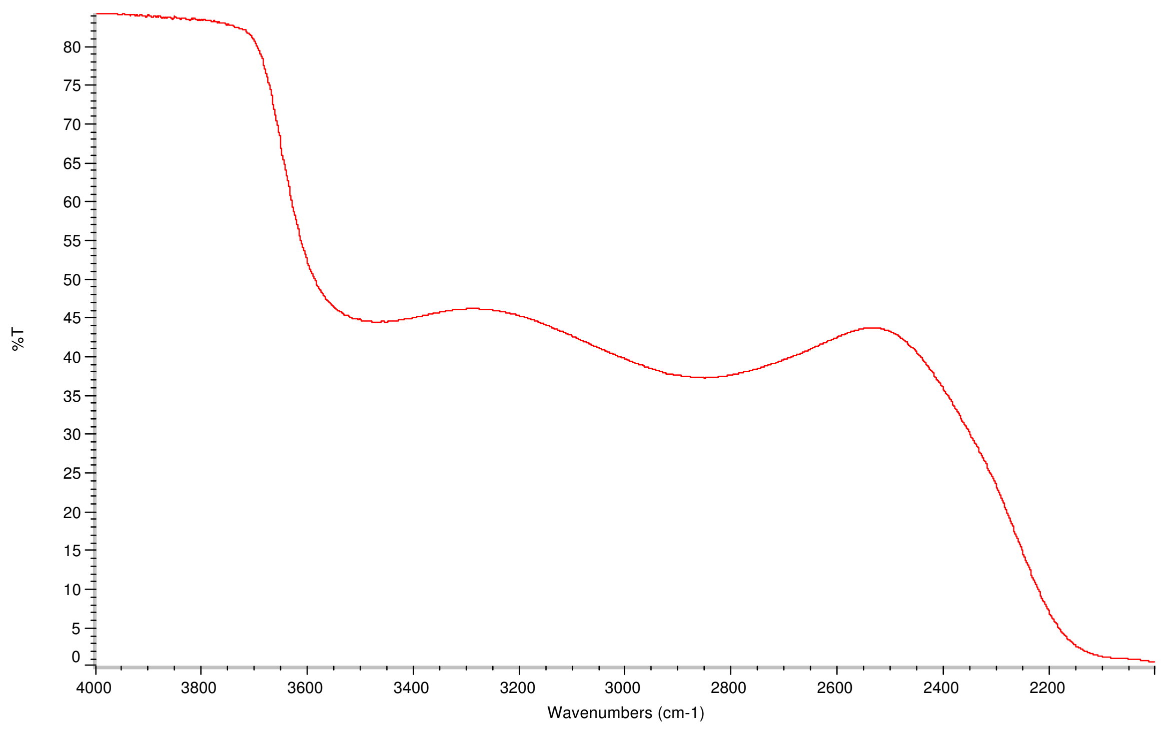
FTIR of bare glass after oxidation.



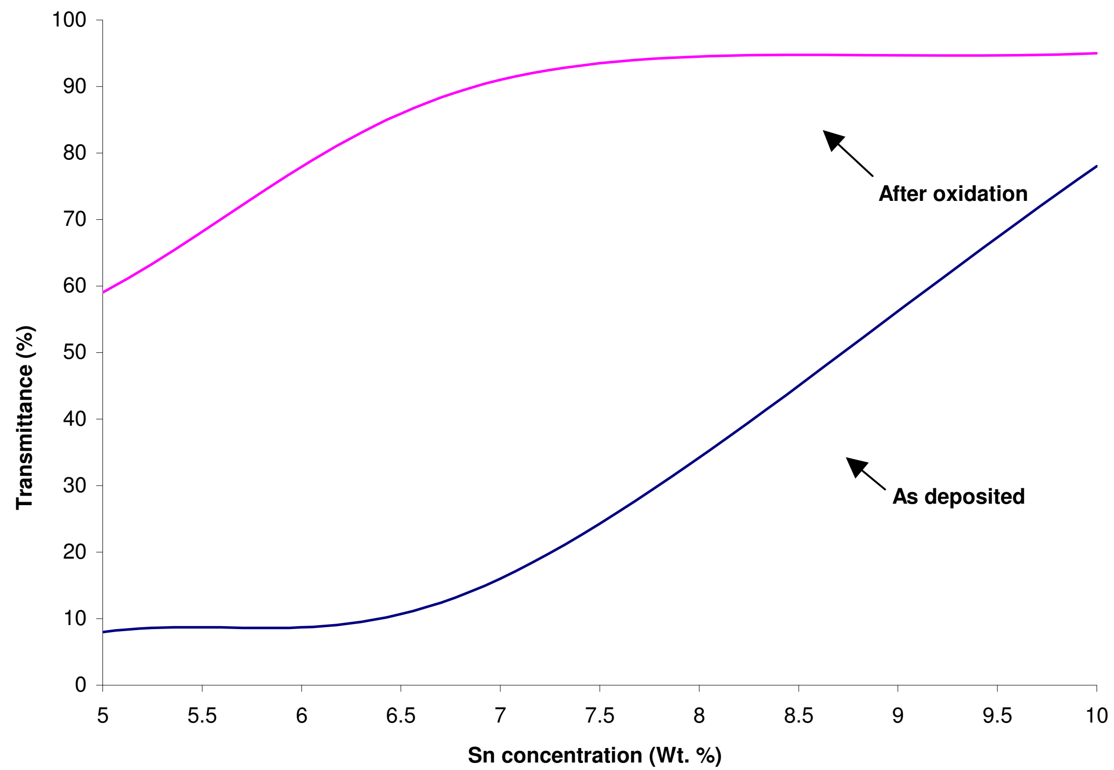
FTIR of In-5%Sn after oxidation



FTIR of In-7%Sn after oxidation



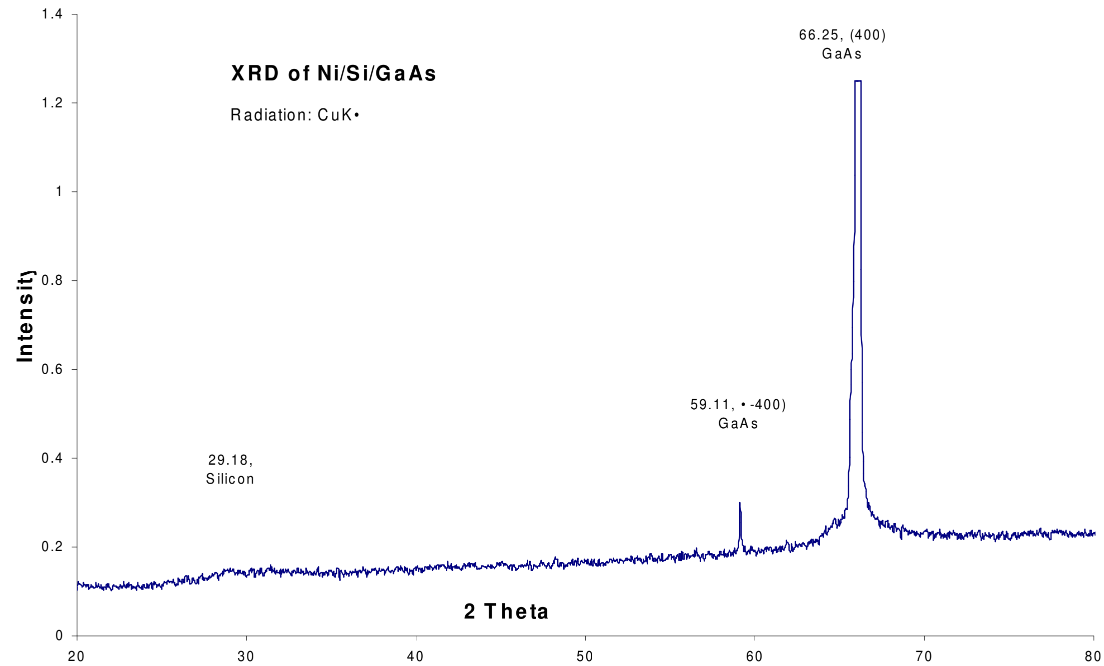
FTIR of In-7%Sn after oxidation



Variation of transmittance with increase in Sn concentration

Silicide Based Contact

XRD of Ni/Si/GaAs



XRD of Ni/Si/GaAs after 1 hour annealing at 350°C

Conclusions:

1. Au-Ge contacts can be reproducibly made as ohmic contacts to GaAs.
2. Indium (or Indium – Tin alloy) deposited, produces highly textured films, oriented along the <101>.
3. The oxidation of the above deposited Indium (or indium- tin alloy) results the formation of highly oriented oxide films (along <111>)
4. Oriented Indium Arsenide could be produced by depositing Indium on Gallium Arsenide and heat treating the sample.
5. It may be possible to use multi-layers of a metal (e.g. Ni) and evaporated silicon to produce novel silicide contacts to GaAs along the lines of the good ohmic contacts produced on Si using various silicides.

Future Scope

1. Sn concentration in the film should be determined and correlated with that in the starting alloy.
2. More detailed electrical characterization of as deposited and oxidized films needs to be done.
3. The variation of electrical and optical properties with Sn composition, deposition parameters, thickness and oxidation time has to be done for the development of transparent conducting oxide.
4. The electrical and optical characterization of silicide based contacts on GaAs should be done to find the possibility of fabricating silicide-based contacts on GaAs.
5. Silicon evaporation on GaAs needs to be optimized and so also the annealing of the deposited layers.