

IX-2

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## AISb/InAs/AISb Quantum Wells

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Much heterostructure and quantum well work is now devoted to materials combinations other than GaAs/(Al,Ga)As. One of the most interesting is the InAs/(Al,Ga)Sb system. In the InAs/GaSb limit, it exhibits a broken gap, which offers a number of interesting possibilities for new kinds of physical phenomena, most of which remain unexplored.

In the InAs/AISb limit, it offers quantum wells of exceptional depth (1.35 eV), combined with the low effective mass ( $0.023 m_0$ ) and high mobilities of InAs, a combination of interest for several potential device applications. The lattice mismatch (1.3%), while not negligible, is sufficiently small that in quantum well structures with well widths of practical interest ( $\leq 10$  nm) the growth should be pseudomorphic, with the mismatch taken up by elastic strain, rather than leading to disastrous misfit dislocation formation.

We have been exploring the InAs/AISb system recently, obtaining 12nm wide quantum wells with room temperature mobilities up to  $28,000 \text{ cm}^2/\text{V}\cdot\text{s}$  and low-temperature mobilities up to  $325,000 \text{ cm}^2/\text{V}\cdot\text{s}$ , both at high electron sheet concentrations in the  $10^{12}/\text{cm}^2$  range (corresponding to *volume* concentrations in the  $10^{18}/\text{cm}^2$  range). These wells were not intentionally doped; the combination of high carrier concentrations and high mobilities suggest that the electrons are due to not-intentional "modulation doping" by an unknown donor in the AISb barriers, presumably a stoichiometric defect, like an antisite donor. Inasmuch as not intentionally doped *bulk* AISb is semi-insulating, the donor must be a deep one, being ionized only by draining into the even deeper InAs quantum well.

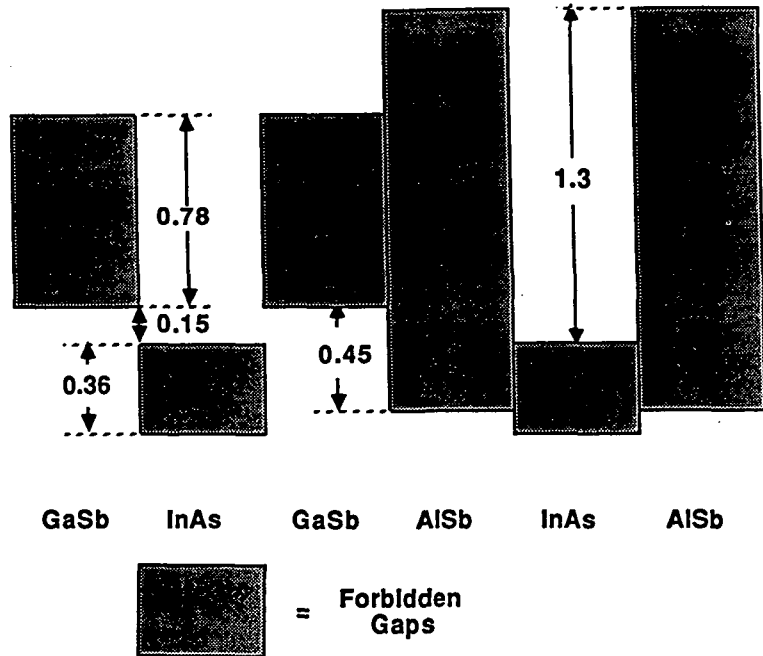
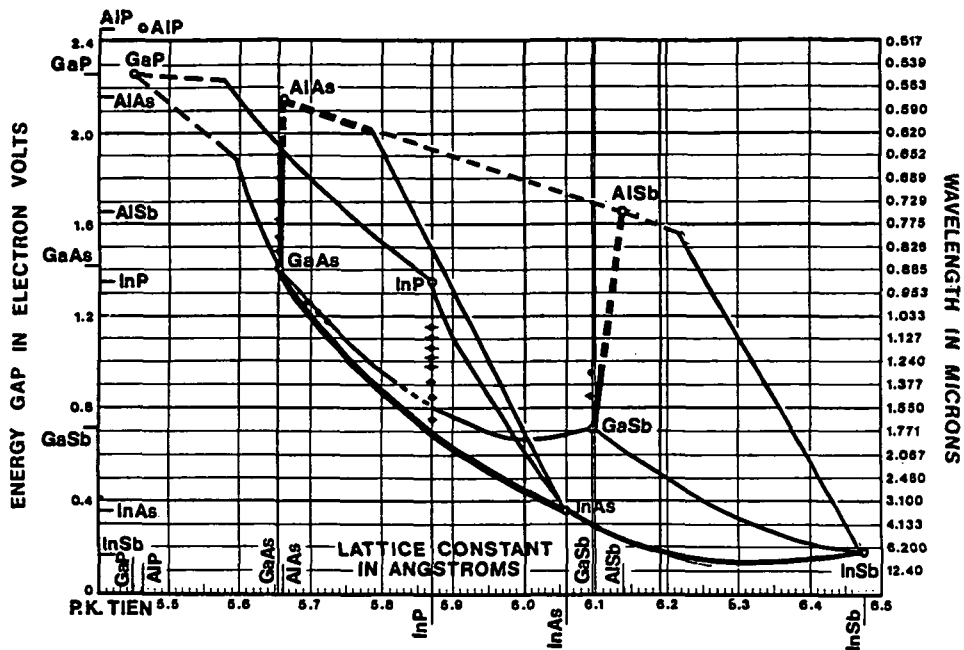
The excellent transport properties are confirmed by other observations, like excellent quantum Hall effect data, and the successful use of the quantum wells as superconductive weak links between Nb electrodes, with unprecedentedly high critical current densities. The system is promising for future FETs, but many processing problems must first be solved. Although

we have achieved FETs, the results so far have not been competitive with GaAs FETs.

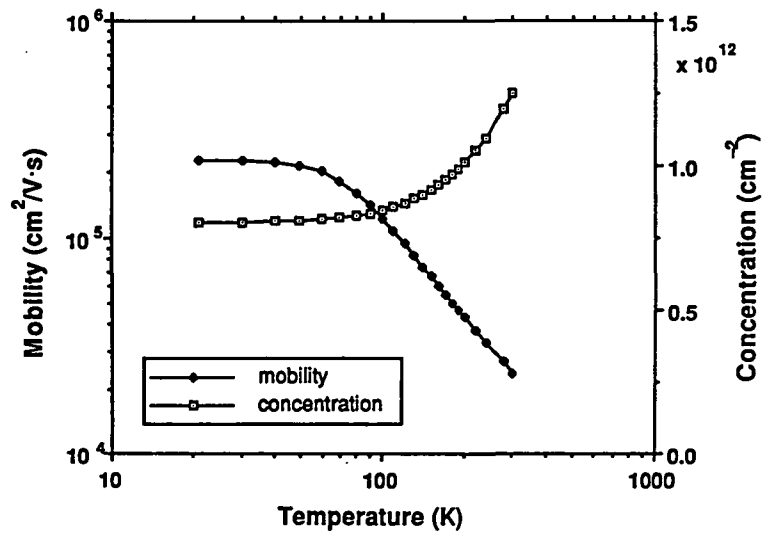
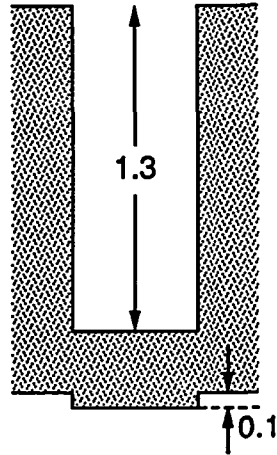
Although most of our work until recently has stressed the transport properties of the system, its optical properties should also be interesting. The large well depths should make the system promising for superlattices with exceedingly short periods. The latter presumably have interesting optical properties, such as strong inter-sub-band absorption effects, of potential use for detector applications. Work exploring the optical properties has been initiated, but we do not have any results to report yet.

Any superlattice applications require particular attention to the quality of the hetero-interfaces, and in this regard the InAs/AlSb system differs *fundamentally* from the GaAs/(Al,Ga)As and (Ga,In)As/(Al,In)As systems: Because both the cation and anion change across an InAs/AlSb (or InAs/GaSb) interface, two distinctly different interface structures may occur. In one case, the InAs would be terminated with a final layer of In, and the adjoining AlSb would start with a layer of Sb, leading to InSb bonds across the interface. We call this the "InSb-like" interface. The complement to this is the "AlAs-like" interface, in which Al atoms from the AlSb side are bonded to As atoms on the InAs side. Experiments show that different kinds of interfaces can indeed be generated by choosing suitable MBE growth parameters, yielding drastically different quantum well properties. All our high-mobility wells were grown under conditions presumably leading to InSb-like interfaces.

A systematic study of the effect of differently grown interfaces showed that wells having AlAs-like *bottom* (i.e. first) interfaces had properties quite different from wells with InSb-like bottom interfaces, while nature of the *upper* (i.e. second) interfaces played little role in determining the properties of the quantum well. More specifically, wells with AlAs-like interfaces at the bottom (but not at the top!) yield a higher electron concentration but much lower mobilities, indicating the presence of a charged defect at those interfaces, believed to be a (deep) As antisite donor on Al sites. Several observations strongly support this interpretation: The magnitude of the effect correlates strongly with the length of exposure of the Al-stabilized AlSb surface to the As flux prior to turning on the In beam. Furthermore, by interrupting the growth of the AlSb barrier some distance away (~10 nm) from the InAs/AlSb interface, and exposing the stagnant AlSb surface to an As flux, we were able to "modulation-dope" the quantum well, with results very similarly to conventional modulation doping with Te donors.



### InAs/AlSb Quantum Wells



Quantization Energy in an Infinitely Deep Quantum Well of Width L:

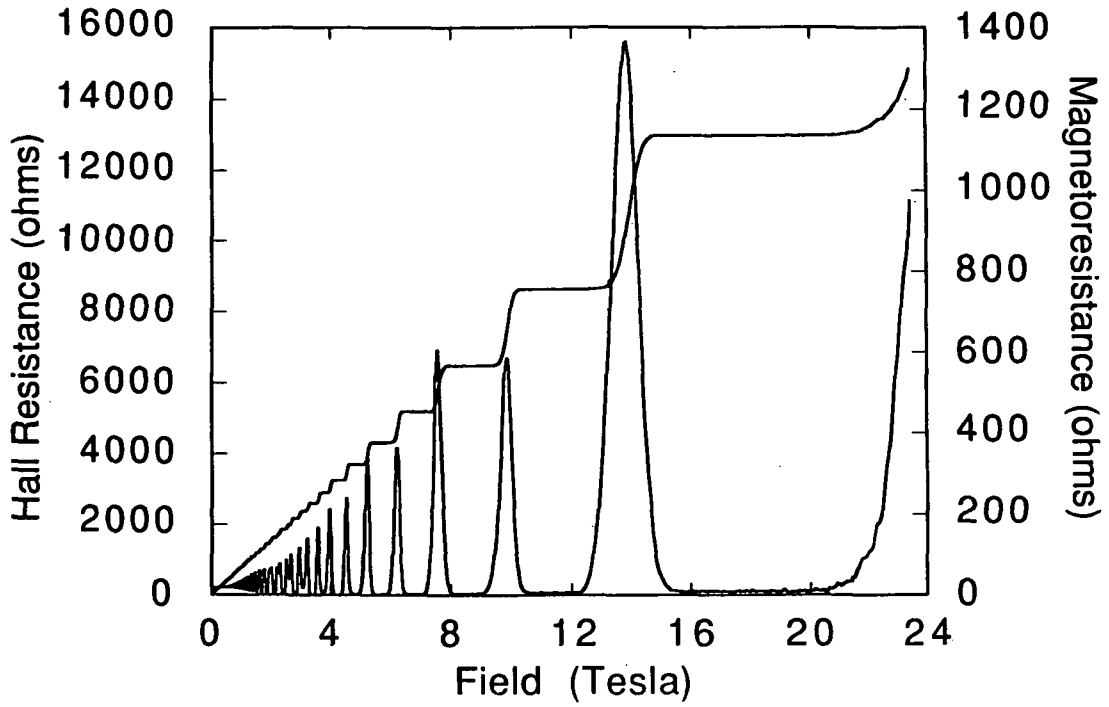
$$\Delta E = \frac{\hbar^2 \pi^2}{2m^* L^2}$$

For  $m^* = 0.026 m_0$  and  $L = 100\text{\AA}$ :

$$\Delta E = 0.145 \text{ eV}$$

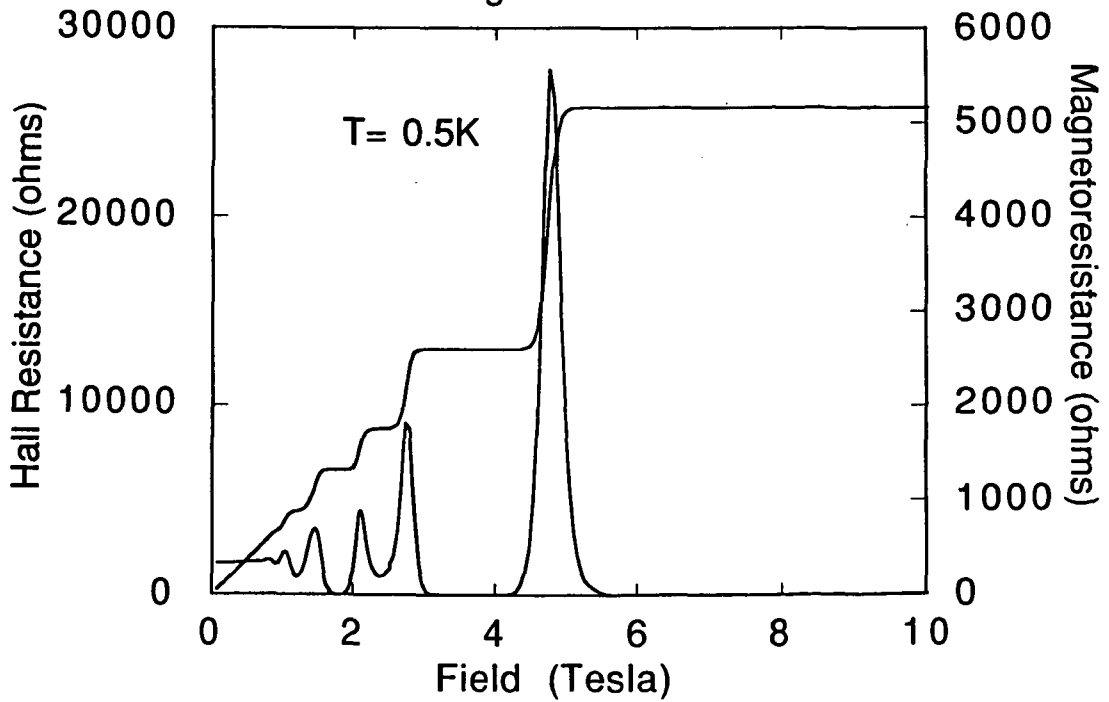
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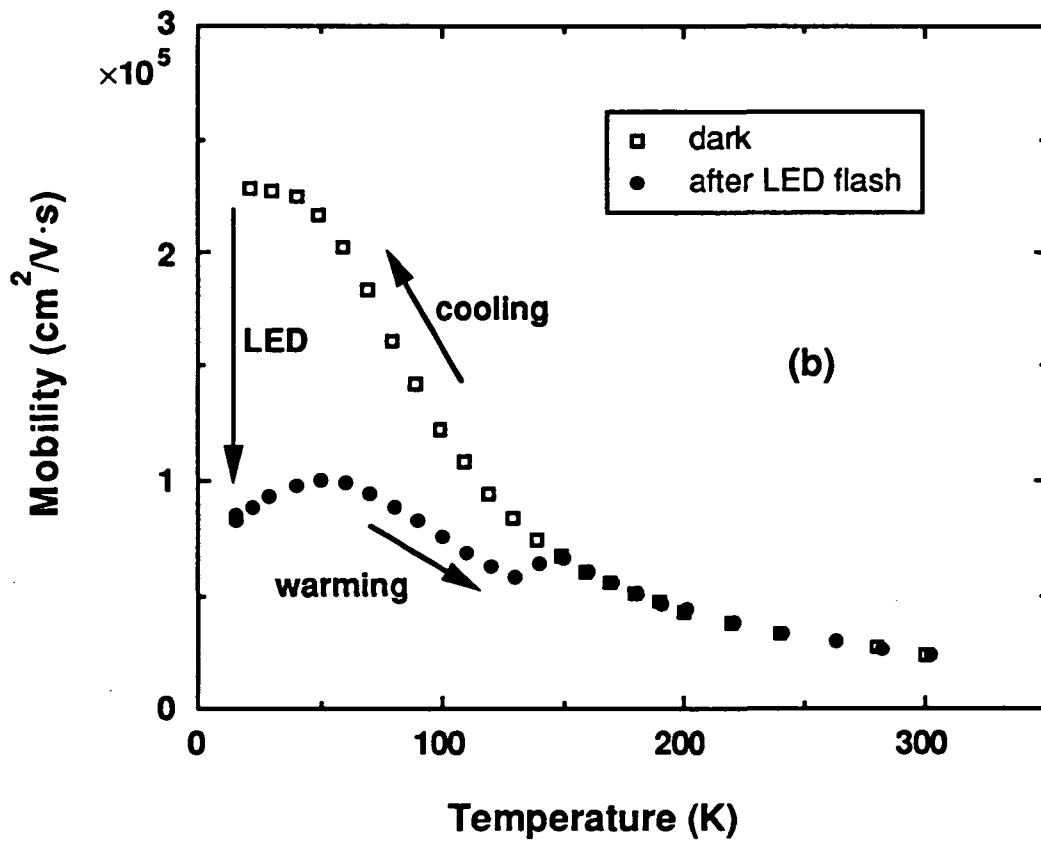
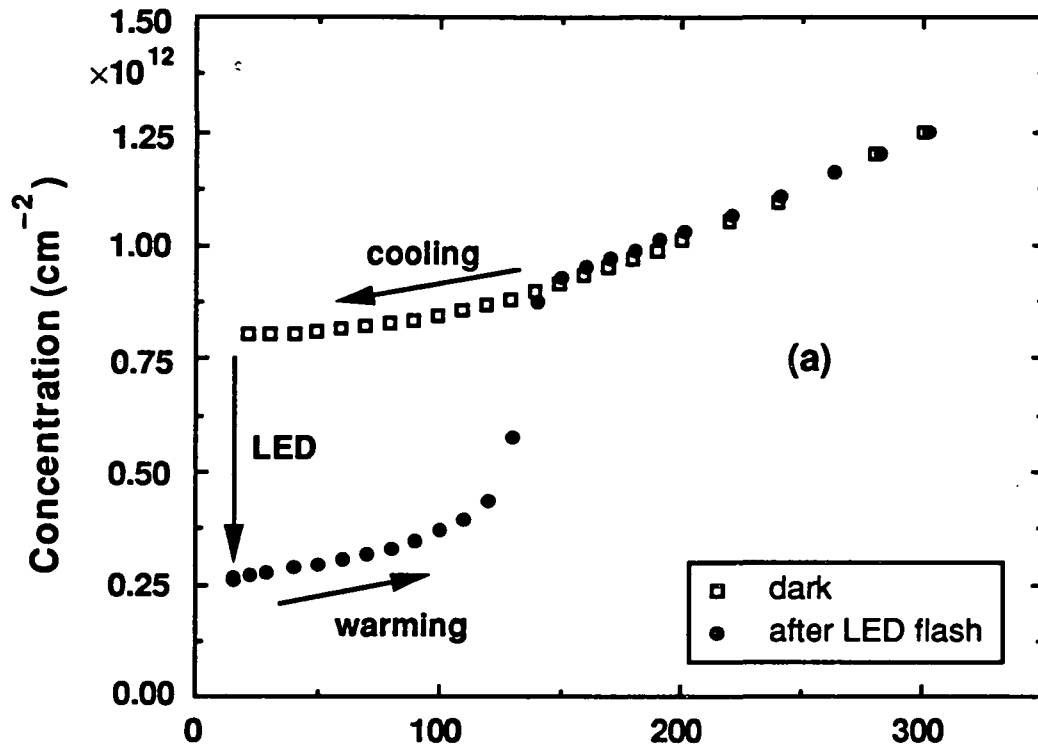
InAs/AlSb 8810-B unilluminated

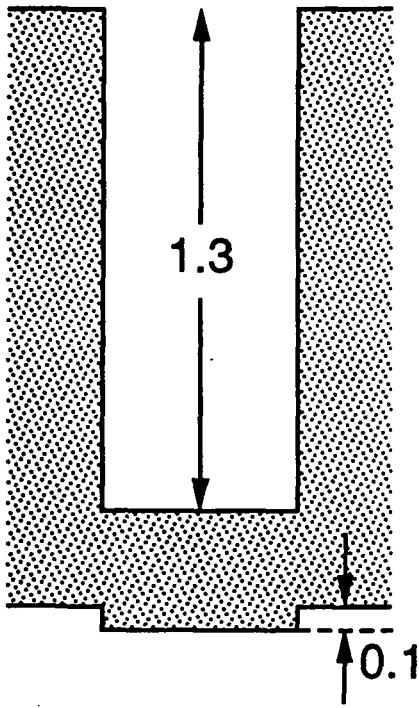


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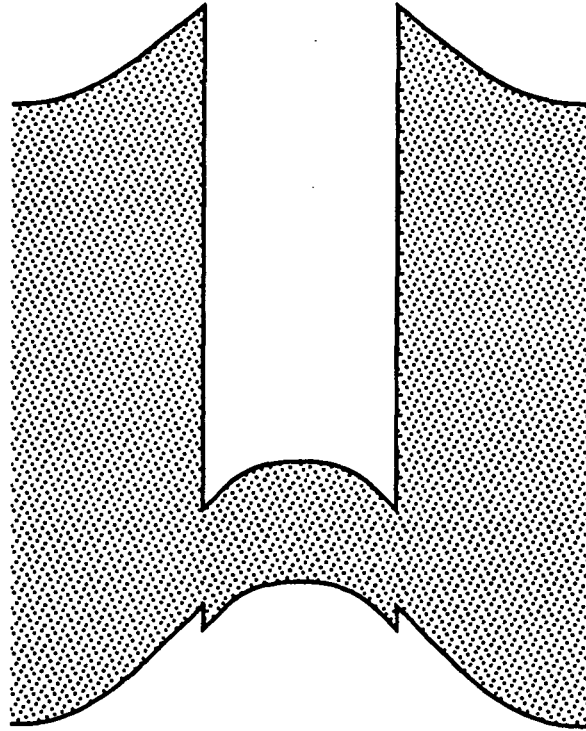
InAs/AlSb green #2 to saturation



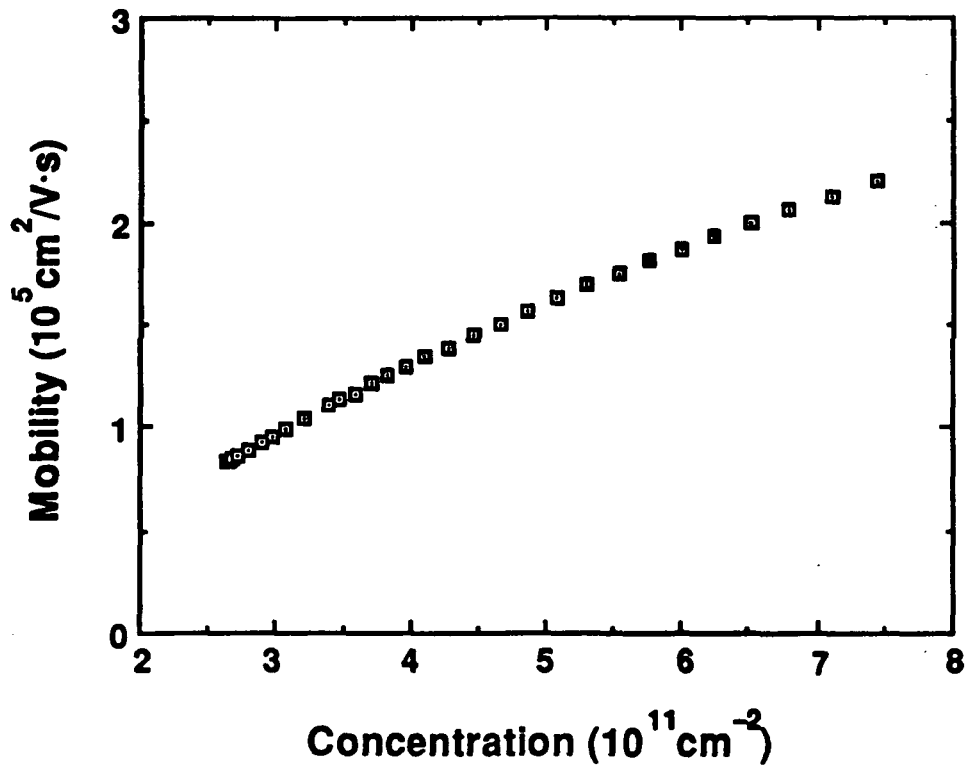


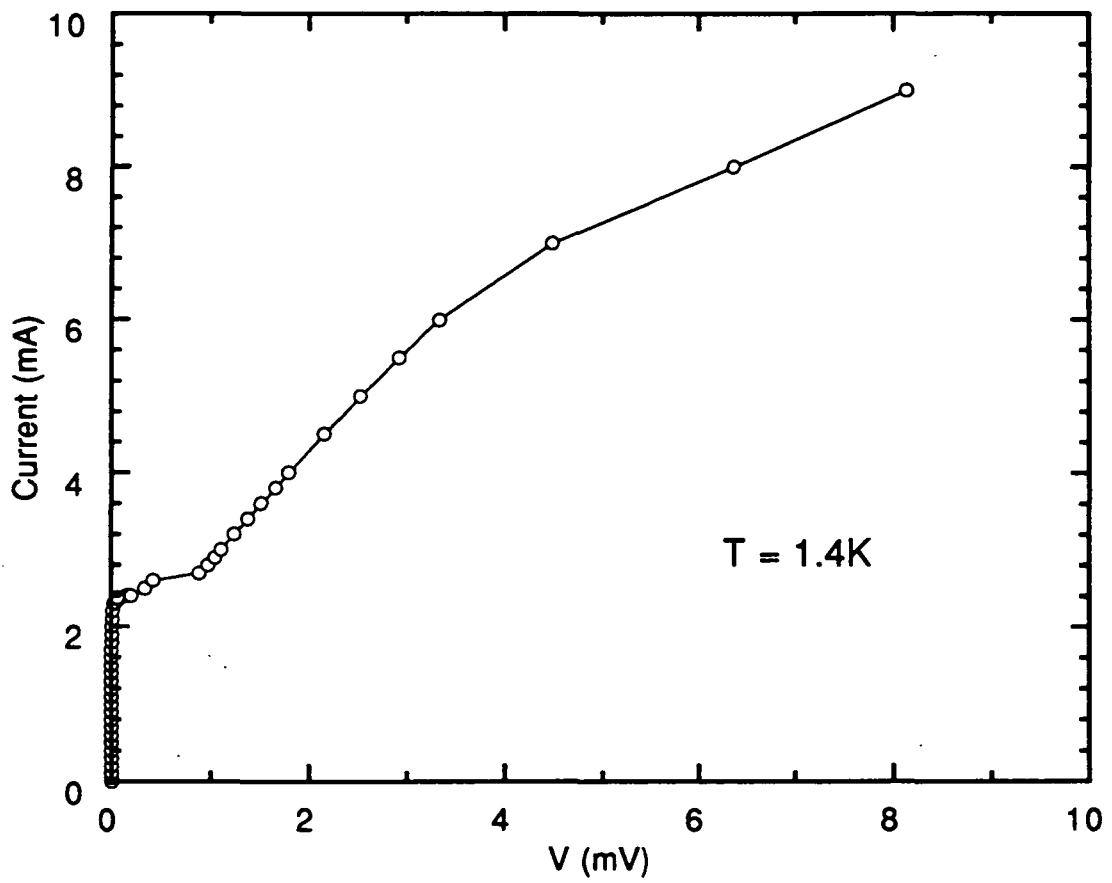
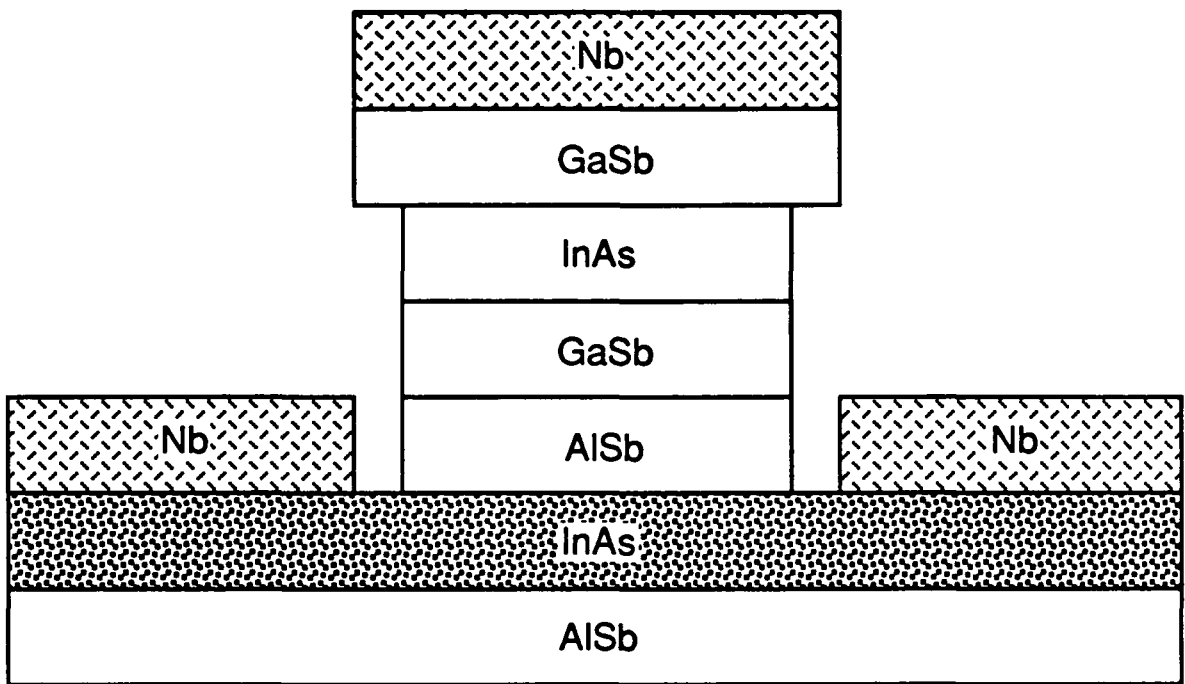


(a)

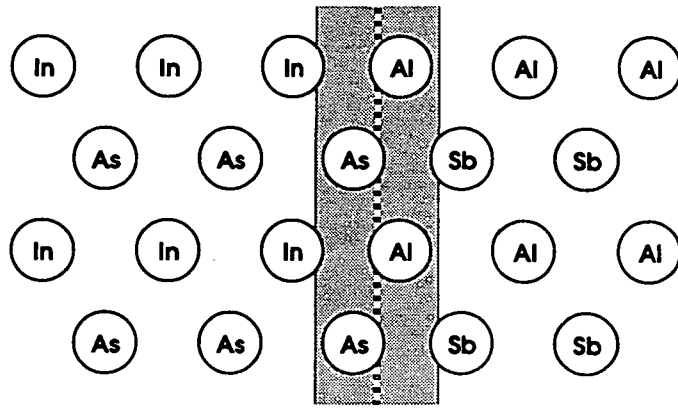


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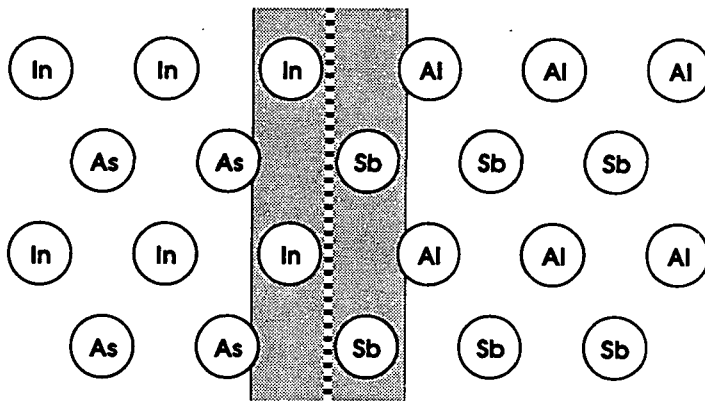




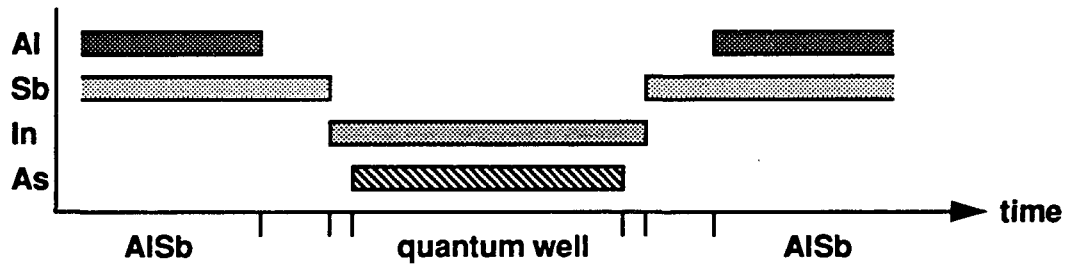




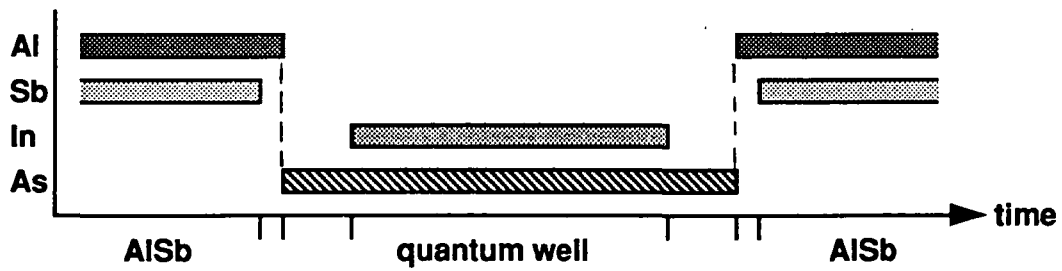
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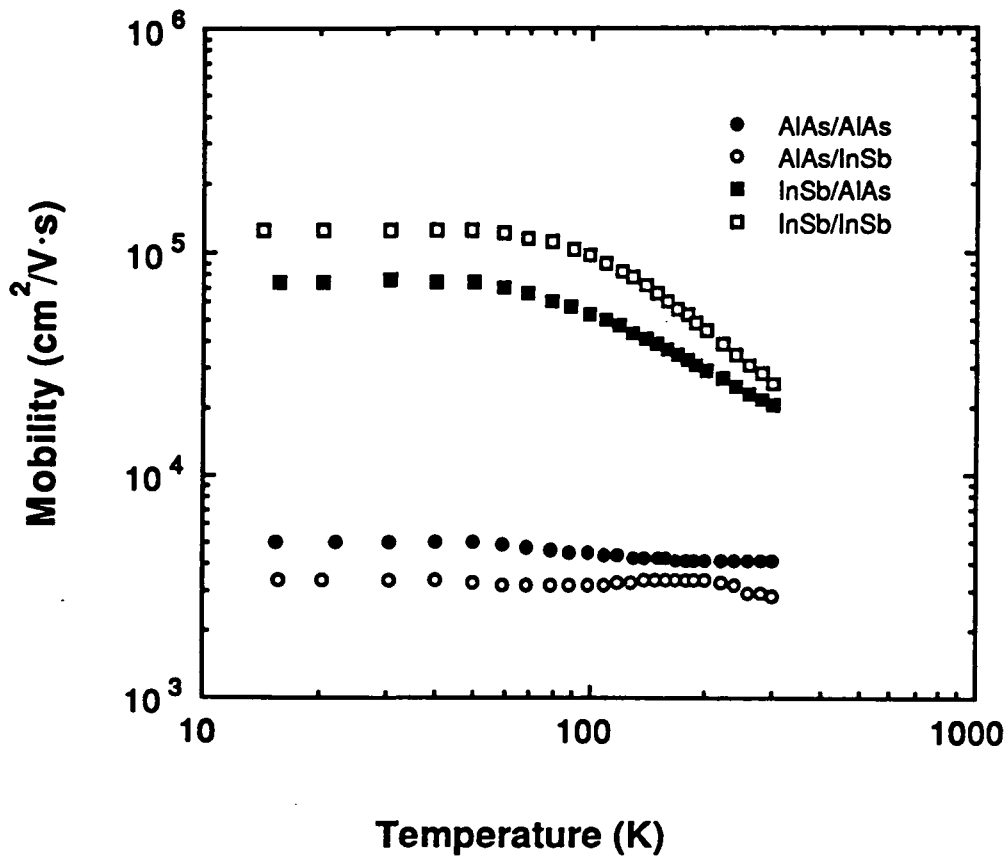
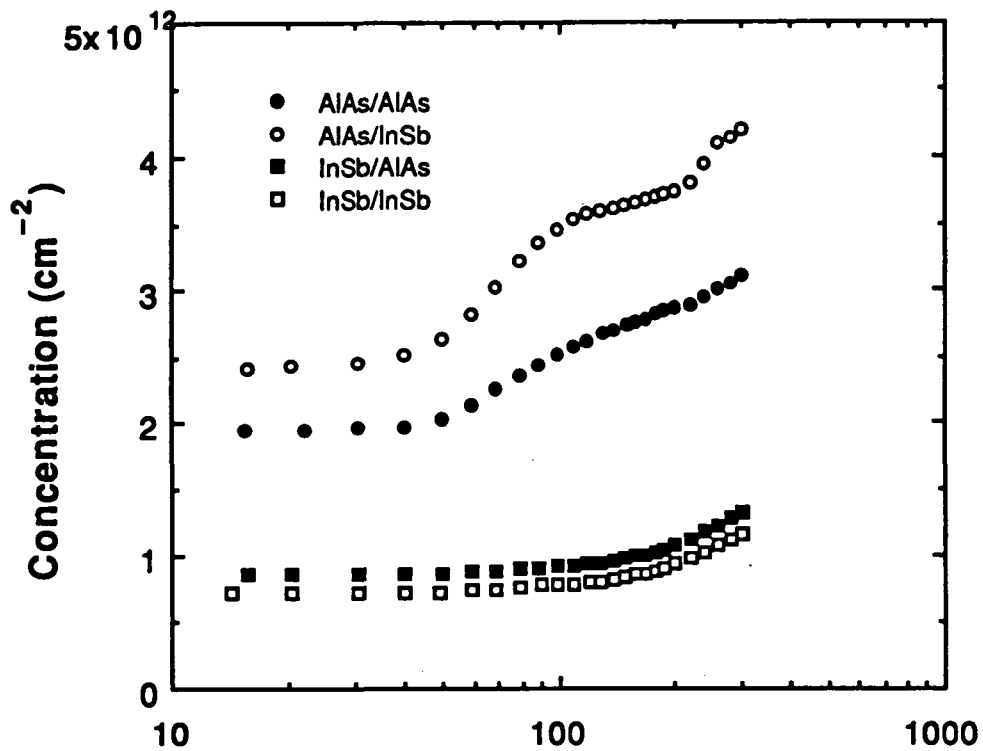
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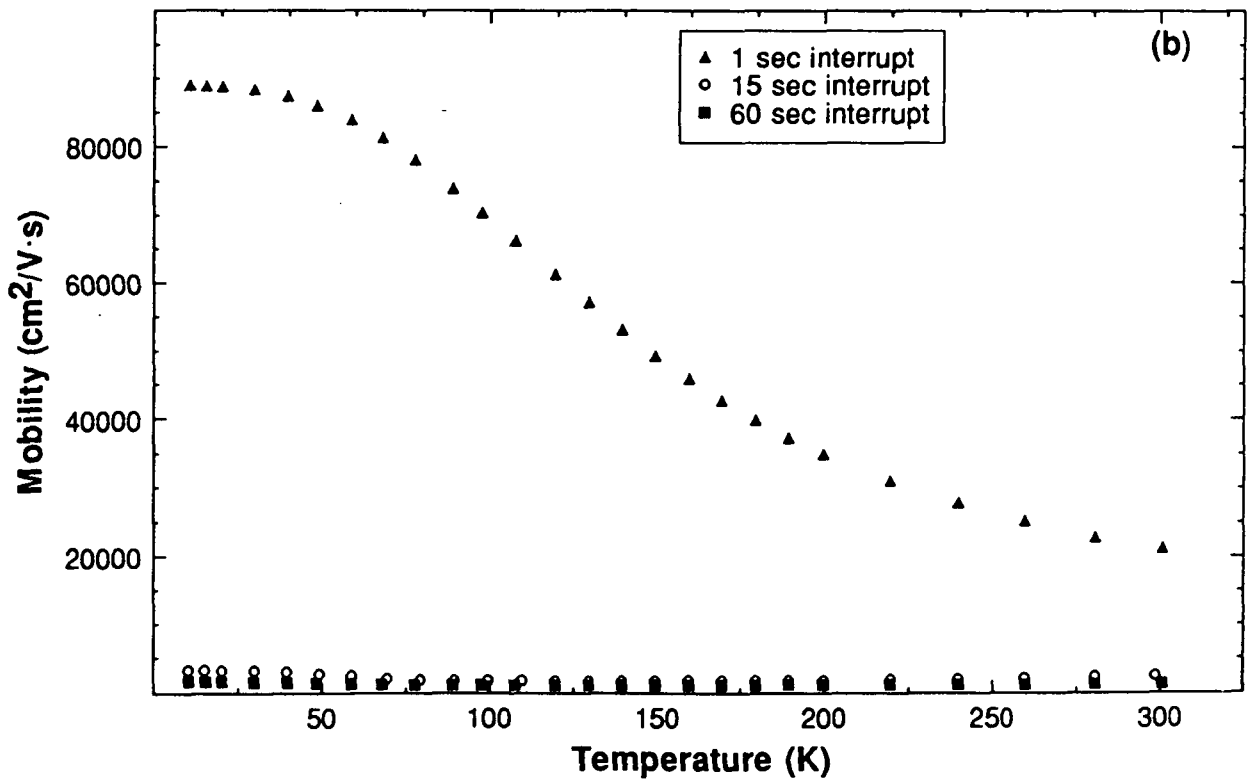
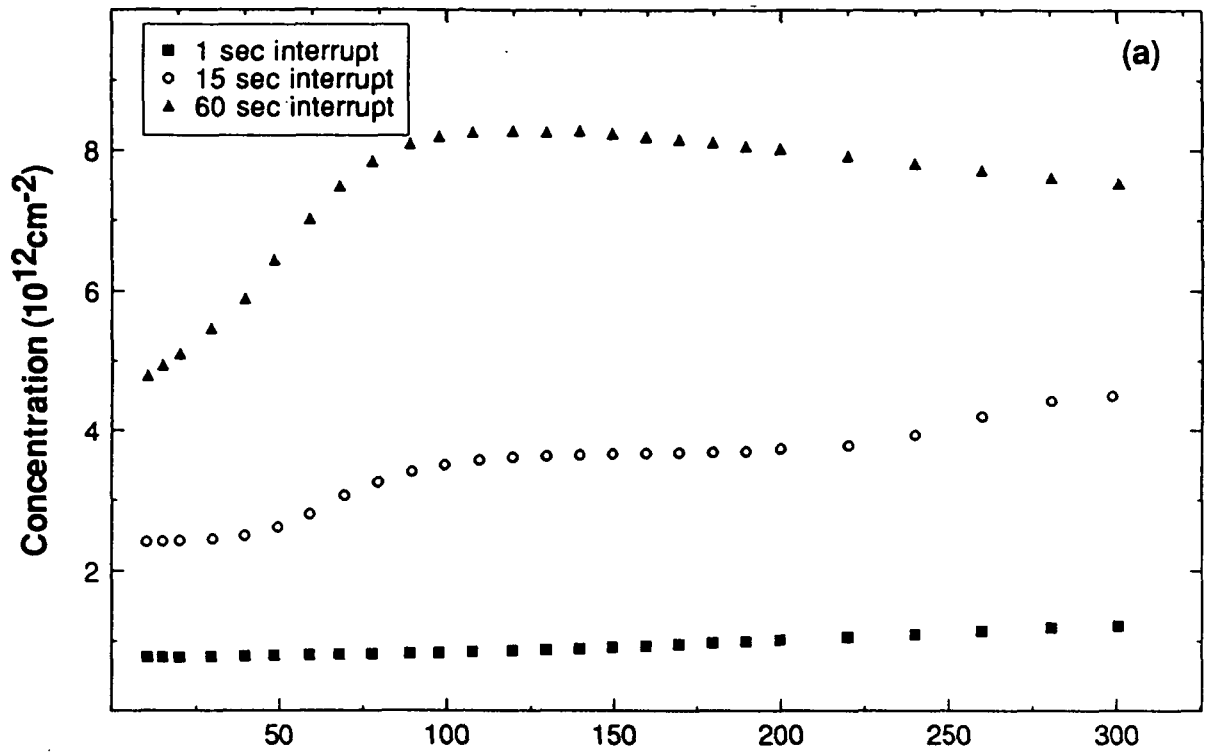


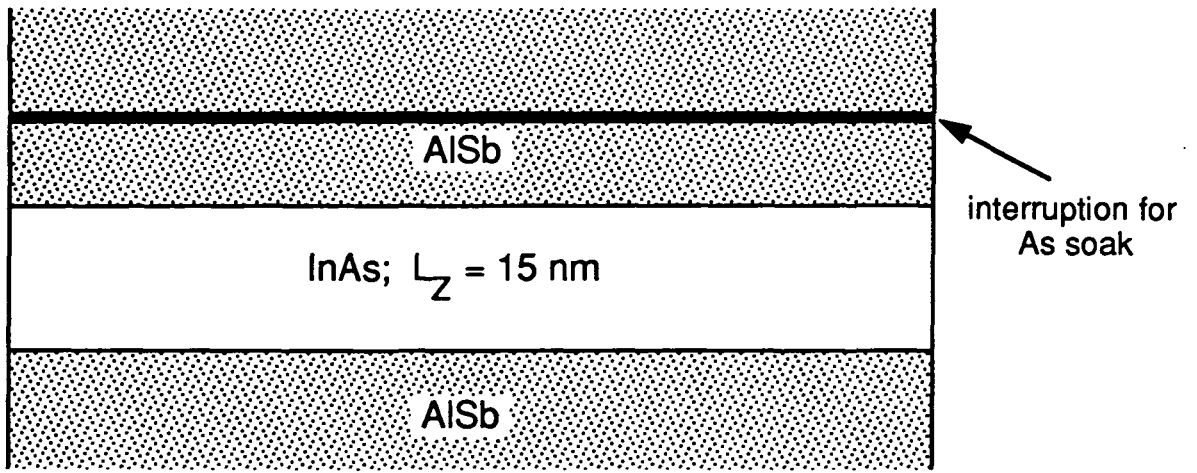
(a)



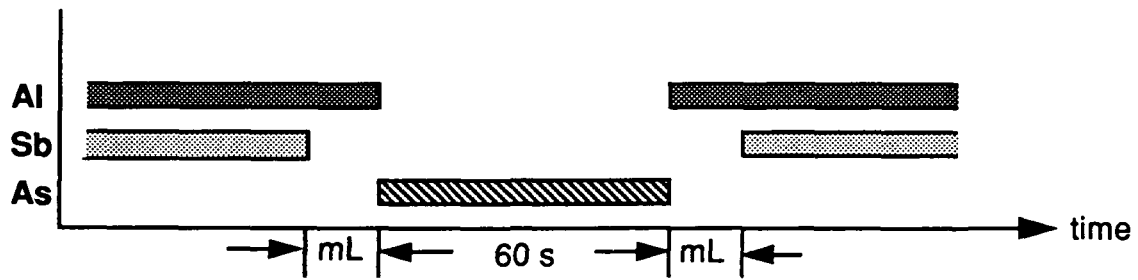
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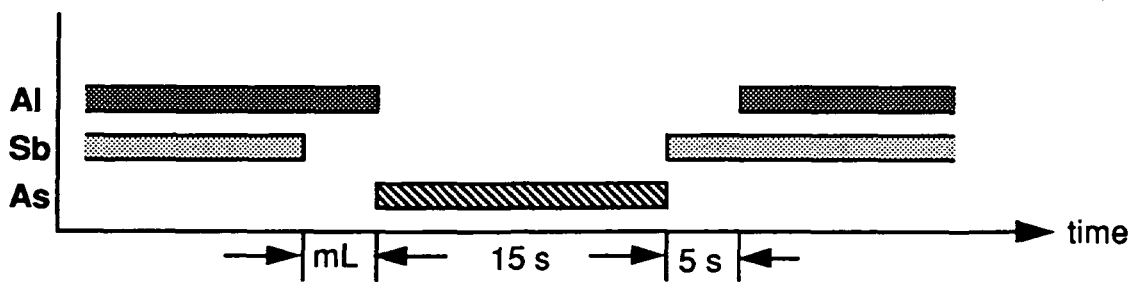




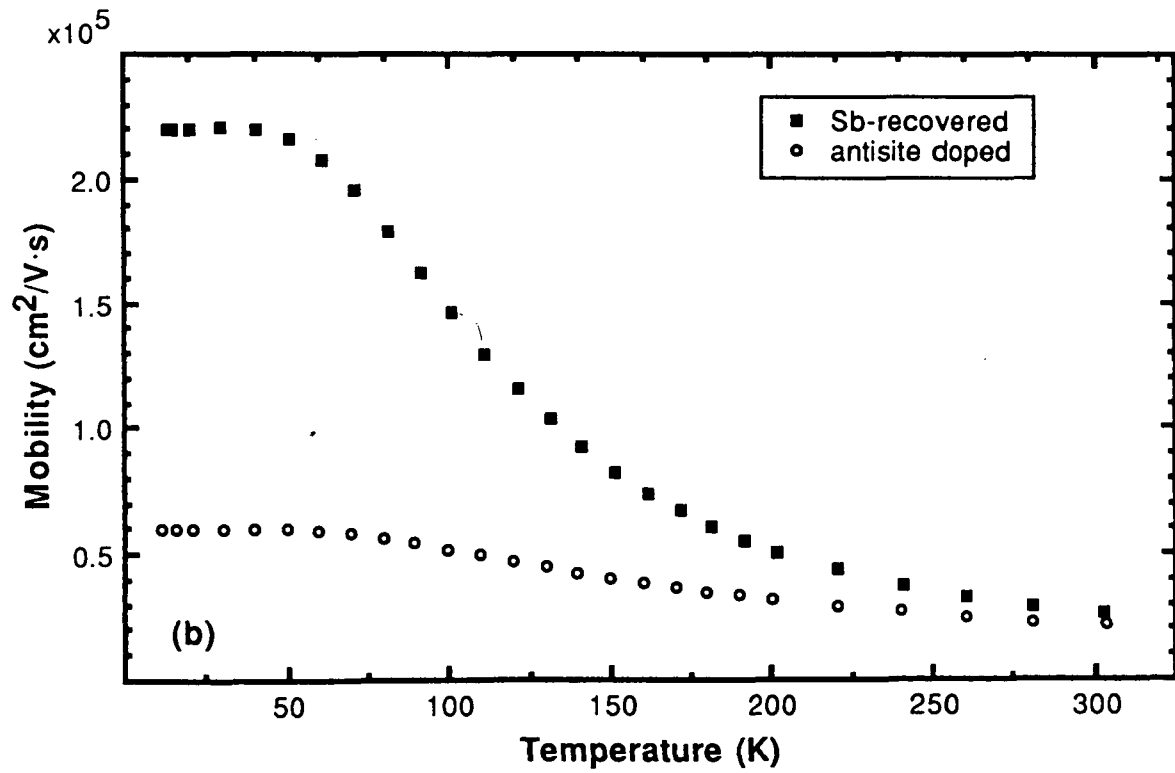
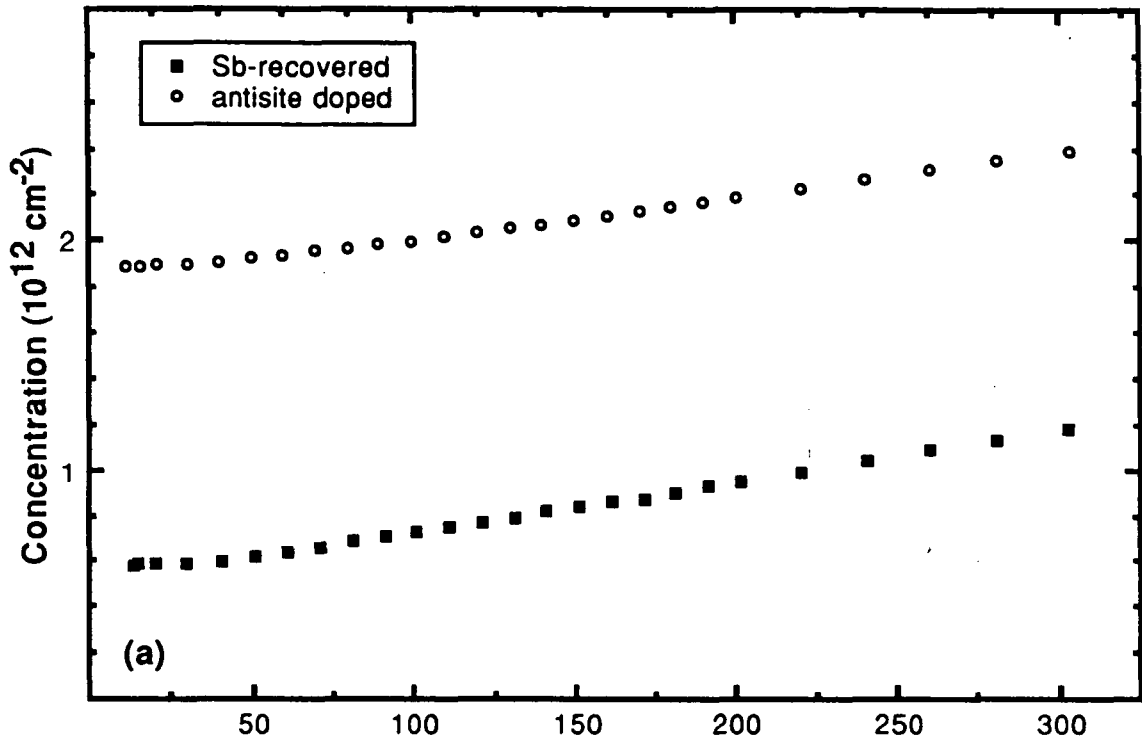
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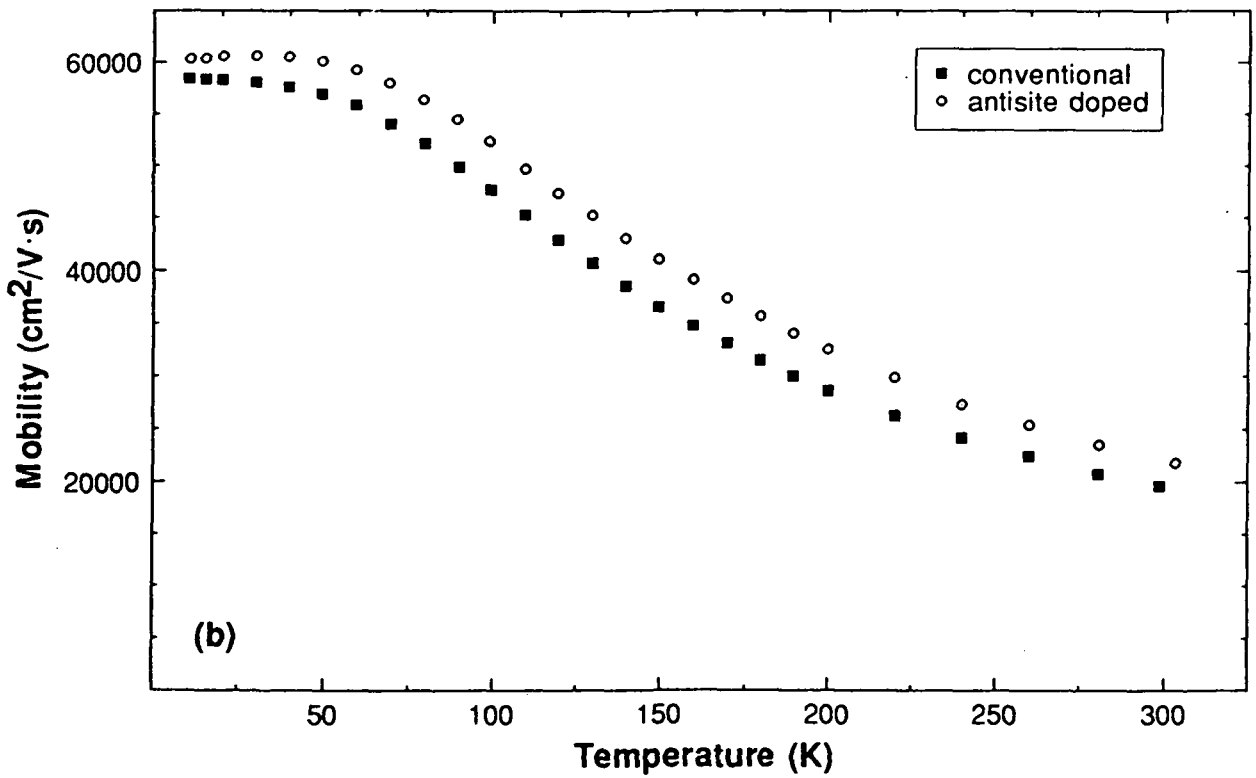
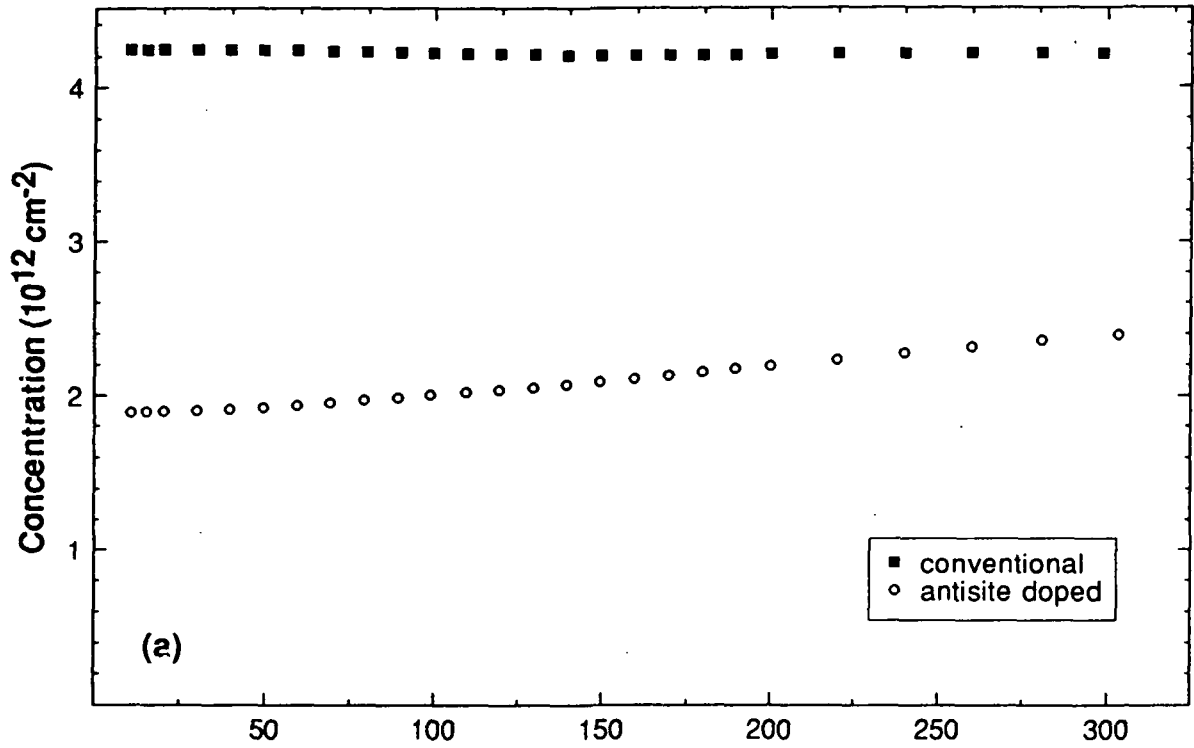


(b)



(c)





### Antisites 100Å below the well

