Temperature Dependent Hole Mobility in MBE grown $GaAs_{1-x}Bi_x$

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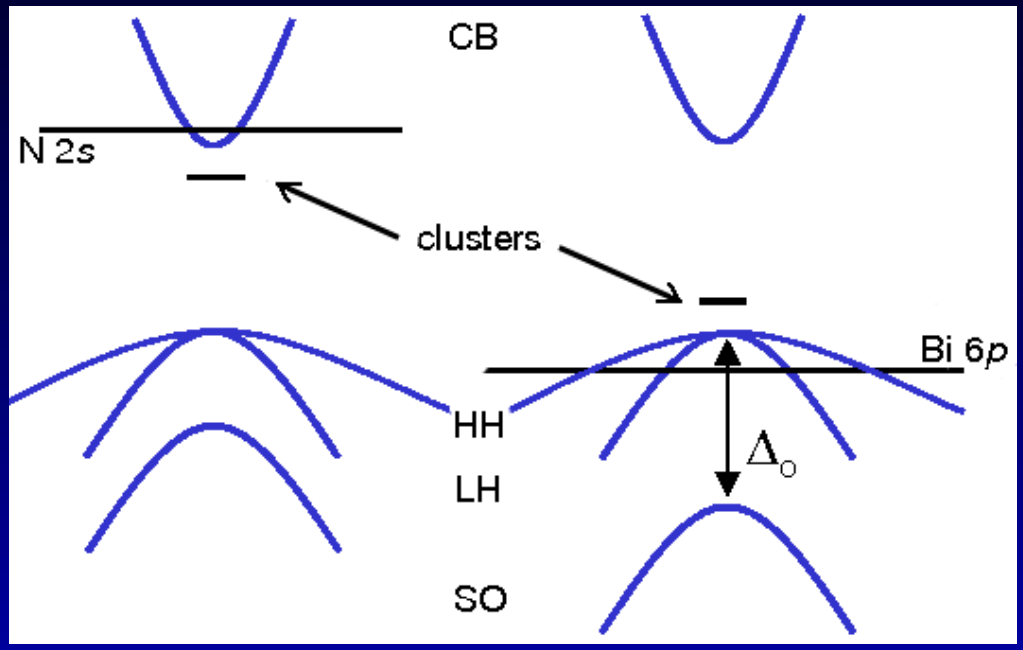
- Sample growth and fabrication
- Growth conditions and hole mobility
- $GaAs_{1-x}Bi_x$ hole mobility
- Temperature dependence

N and Bi in GaAs



- Nitrogen perturbs the conduction band and reduces electron mobility
- Expect Bismuth to perturb valence band and effect hole mobility

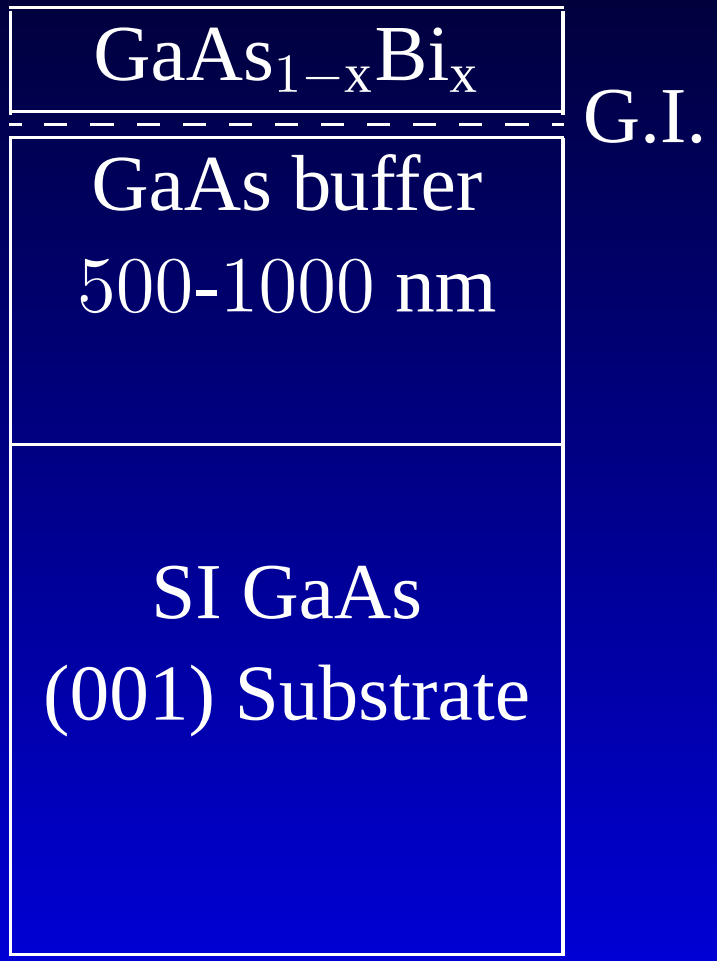
MBE Growth of $GaAs_{1-x}Bi_x$

GaAs buffer

- $T_{grow} \simeq 580°C$
- As:Ga ratio $\simeq 8$
- Growth rate $\simeq 1\ \mu$m/hr
- Ga BEP $\simeq 2\text{x}10^{-7}$ Torr

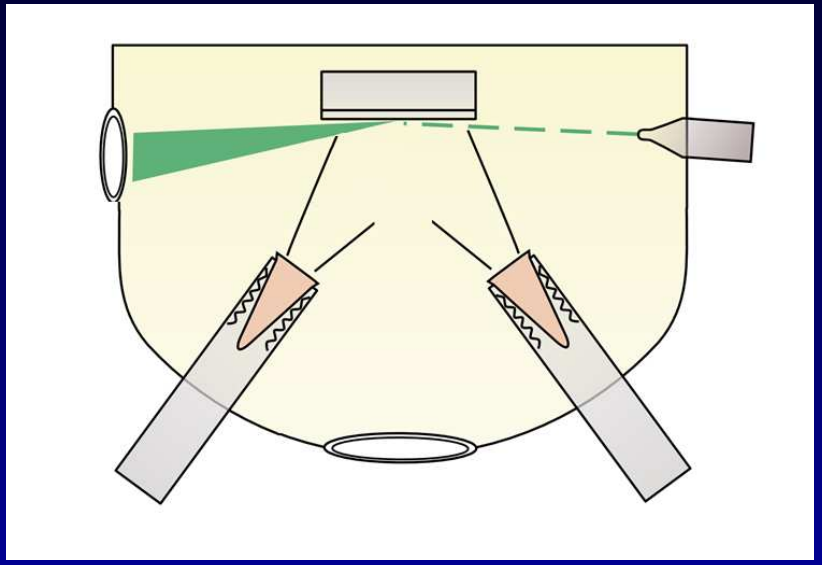
GaAsBi

- $T_{grow} \simeq 350°C$
- Growth rate $\simeq 0.1\ \mu$m/hr
- As:Ga ratio $\simeq 1 - 2.0$
- Bi BEP $\simeq 5\text{x}10^{-10}$ Torr



MBE Growth

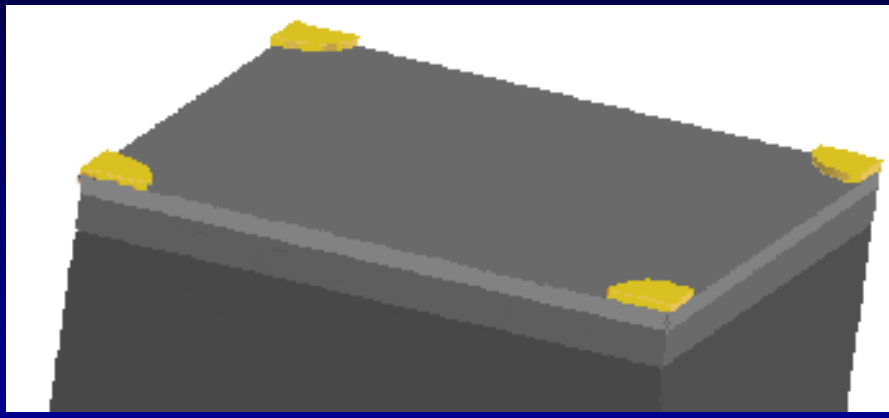
- Effusion cells for Ga, Bi
- Valved two-zone cracker for As_2
- Carbon dopant from CBr_4 flow controlled gas source
- *In-situ*: Band gap thermometry, RHEED, Light scattering



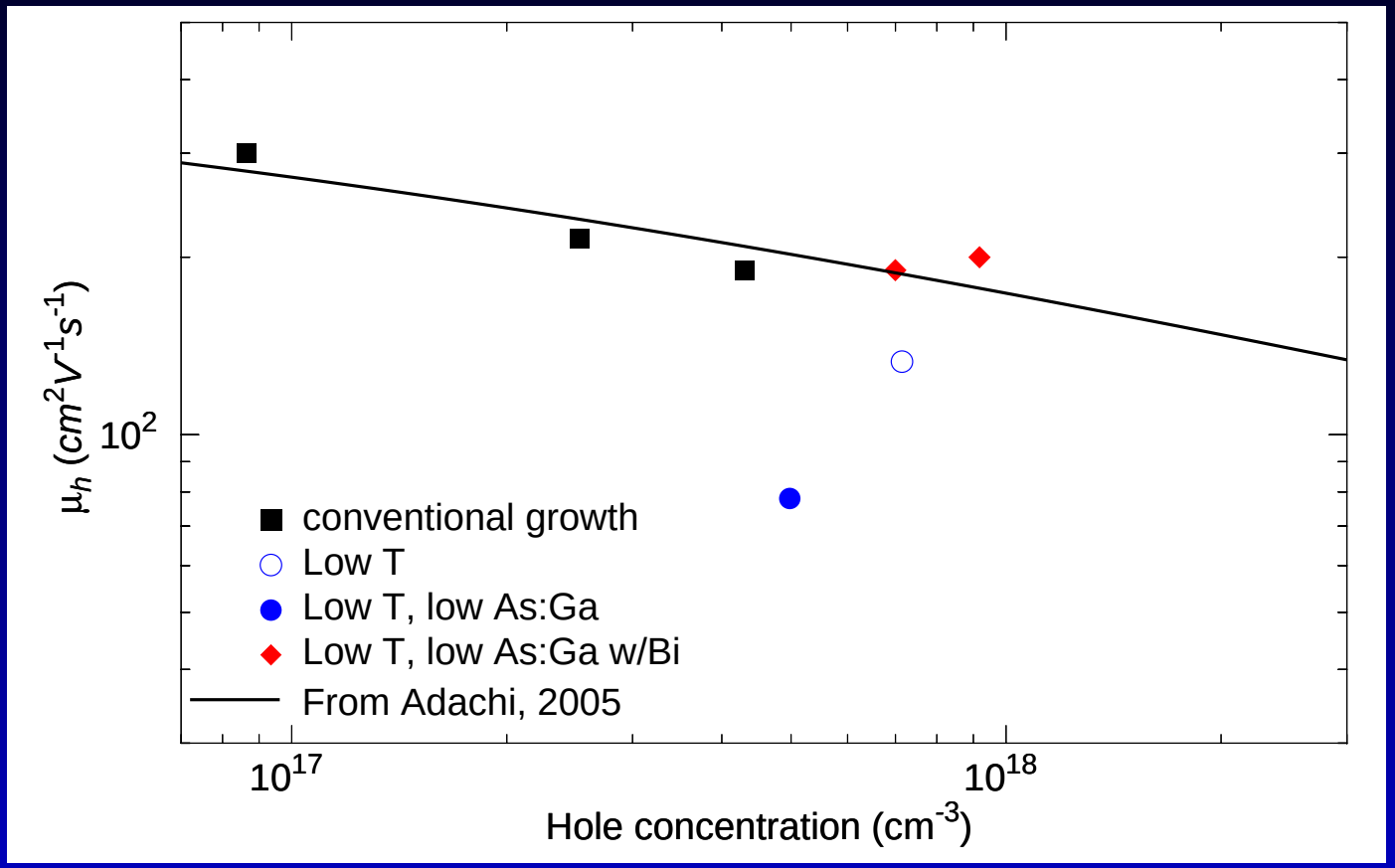
VG-80H MBE Chamber

Hall Measurements

- Thicknesses $250 - 1000$ nm
- Doping: $8\text{x}10^{16}$-$2\text{x}10^{18}\text{cm}^{-3}$
- Depletion widths=70-20nm
- 7×7 mm squares
- Ti/Pt/Au Ohmic contacts
- Van der Pauw method
- B = 0.265 T
- Temperatures of 25-300 K

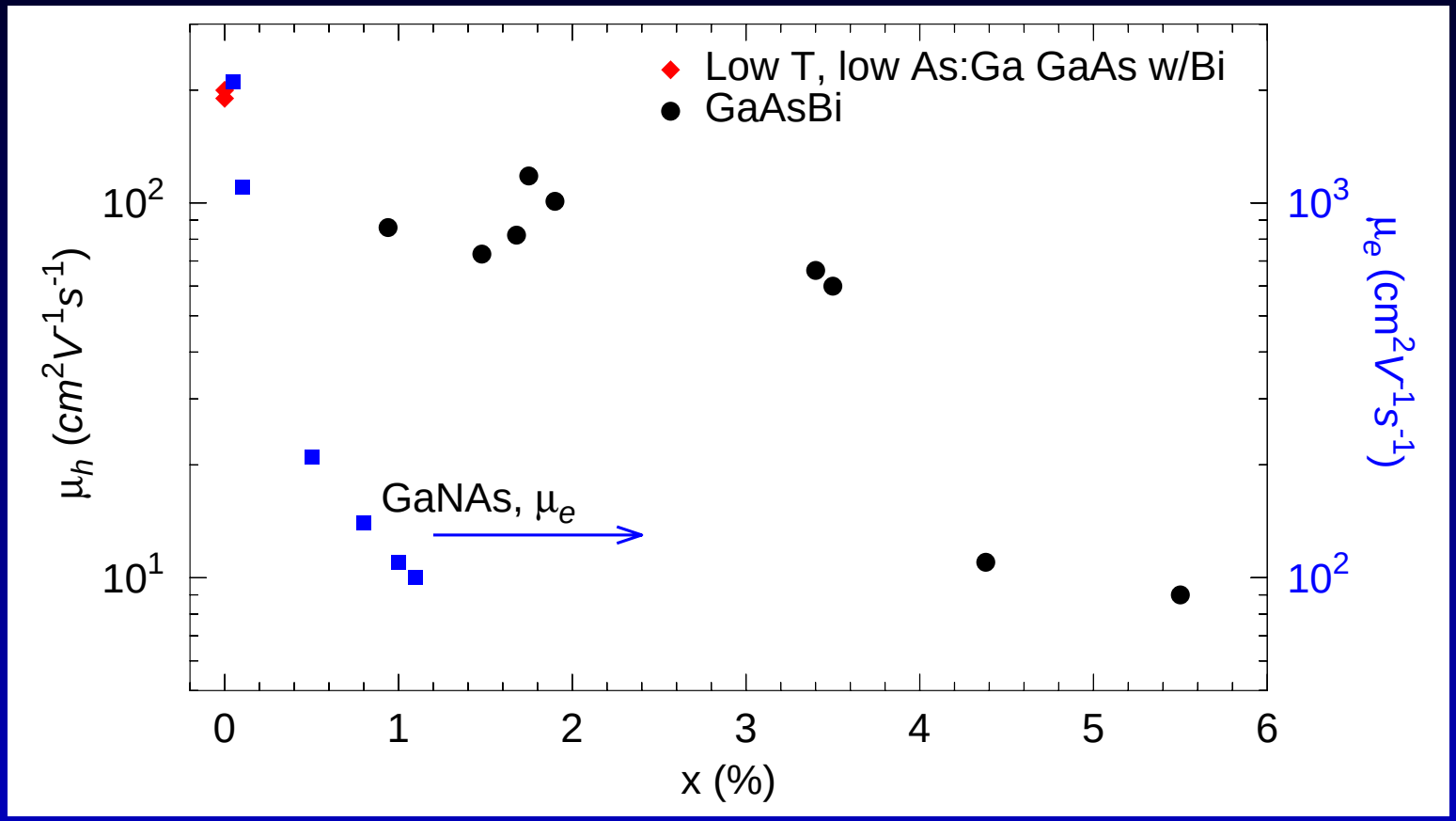


Hole Mobility of p-GaAs



- Low temperature growth of GaAs with Bi surfactant shows no reduction in hole mobility

Hole Mobility of p-$GaAs_{1-x}Bi_x$



- Hole mobility decreases with increasing [Bi]
- Effect weaker than N incorporation on electron mobility

Mobility Temp. Dep.

- Contributions from phonons, ionized impurities and Bi incorporation

$$\frac{1}{\mu} = \frac{1}{C_{\text{ph}} T^{1.5}} + \frac{T^{1.5}}{C_{\text{I}}} + \frac{1}{C_{\text{Bi}}}$$

- Kinetic Theory; $\frac{1}{N_{\text{Bi}}\sigma} = \frac{v\ m^* C_{Bi}}{q}$
- Fahy *et al.* [1]; $\sigma = \frac{1}{16\pi}\left(\frac{m^*}{\hbar^2}\right)^2 \left(\frac{dE_g}{d\text{x}}\right)^2 a^6$

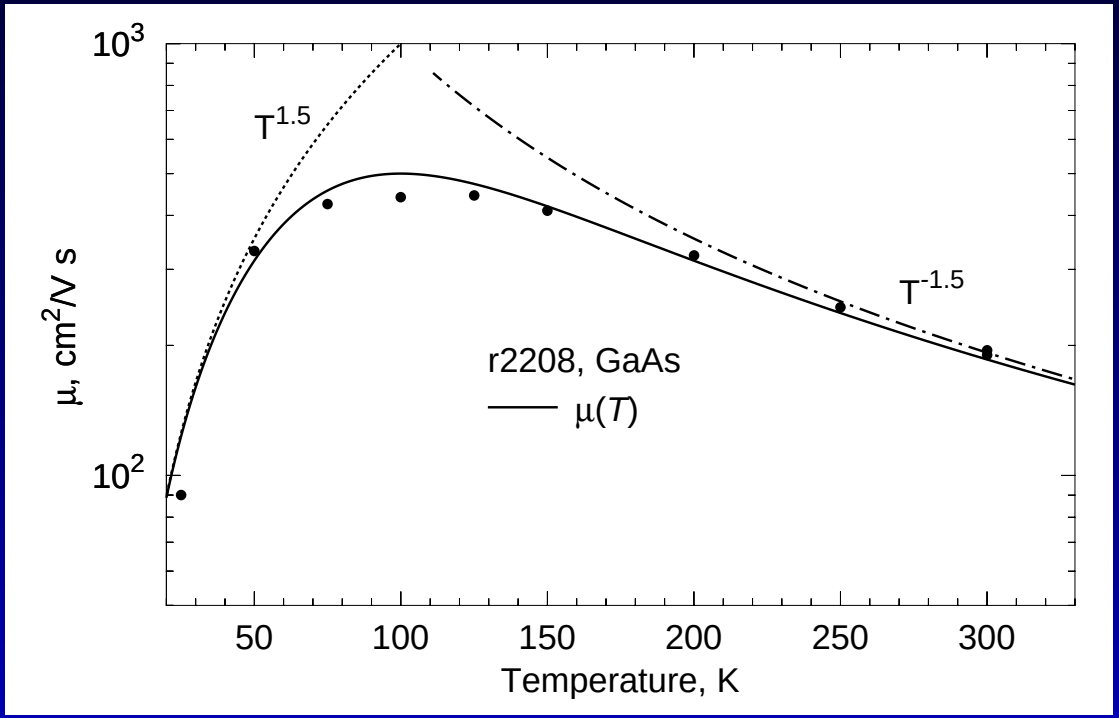
a is GaAs lattice parameter, $\frac{dE_g}{d\text{x}} = 8.8$ eV

$$\rightarrow \ \sigma = 2.0 \text{ nm}^2$$

[1] S. Fahy, A. Lindsay and E.P. O'Reilly, IEE Proc. Optoelectron. **151**, 352 (2004)

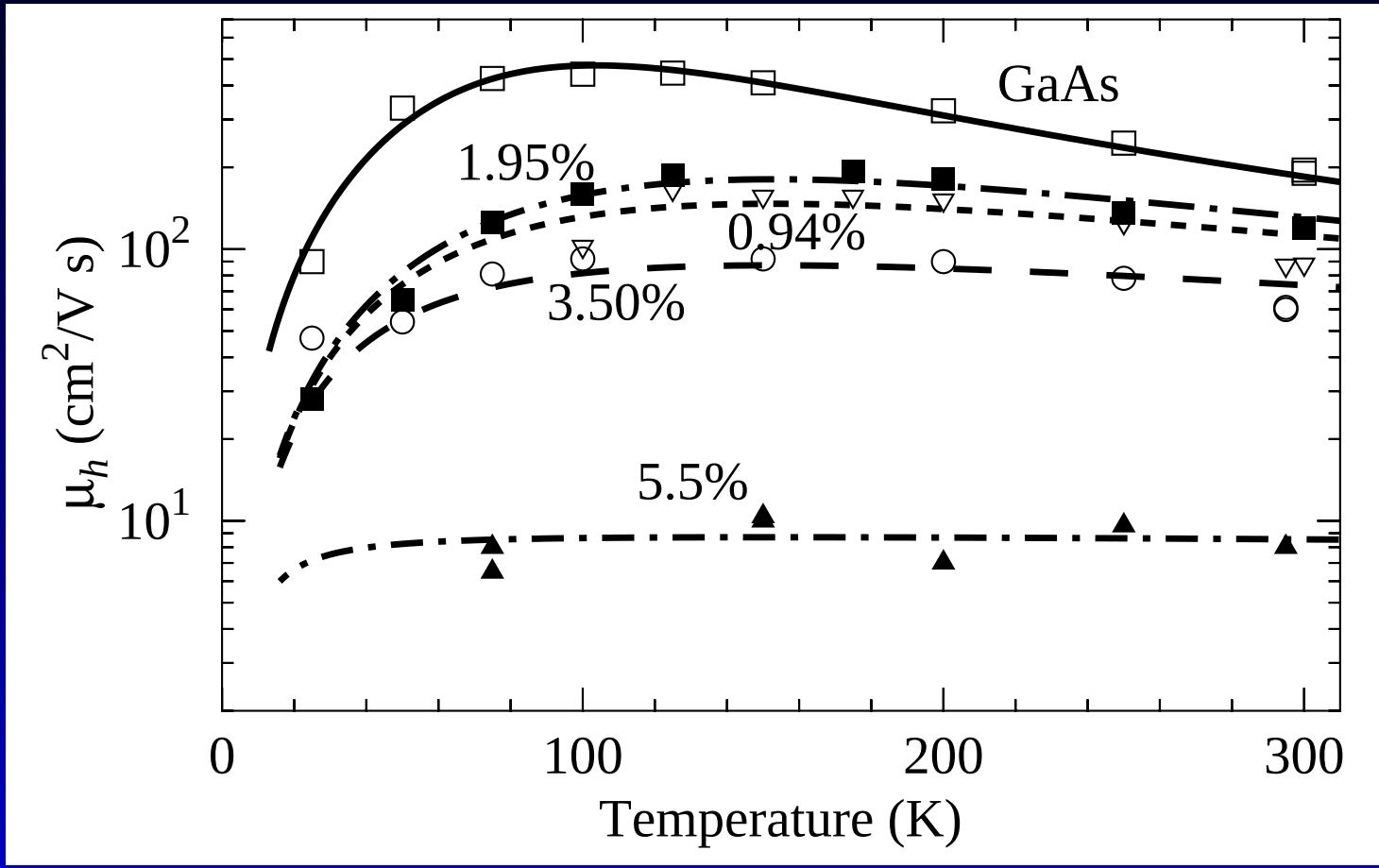
Mobility Temp. Dep. in GaAs

$T_{grow} = 350°C$; As:Ga$\simeq 2$; w/ Bi surfactant



- Bismide-like growth conditions, $GaAs_{1-x}Bi_x$ $x = 0$
- Will use C_{ph} from this sample for $GaAs_{1-x}Bi_x$ samples

Mobility Temp. Dep. in $GaAs_{1-x}Bi_x$



- Increasing effect from C_{Bi} with increasing [Bi]

Mobility Temp. Dep. in $GaAs_{1-x}Bi_x$

[Bi] (%)	0%	0.94%	1.95%	3.5%	5.5%
$\mu(300K)\ \left(\frac{cm^2}{V\ s}\right)$	200	88	100	60	8
C_{ph}	1.0×10^6	1.0×10^6	1.0×10^6	1.0×10^6	-
C_I	0.9	0.28	0.28	0.28	0.28
C_{Bi}	-	330	570	130	9

$\Downarrow$ $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ $\Downarrow$

isolated Bi, $\sigma_{\mathrm{Bi}} = 0.2\ \mathrm{nm}^2$ $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ $2.0\ \mathrm{nm}^2$

Conclusions

- Low temperature growth of GaAs with Bi surfactant shows no reduction in hole mobility
- Decreasing hole mobility for increasing [Bi] in $GaAs_{1-x}Bi_x$ up to x$= 5.5\%$
- Weaker effect than decreasing electron mobility in GaN_xAs_{1-x}
- Effect of Bi modeled with temperature independent term
- Estimated $\sigma = 0.2$-2.0 nm^2

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Thank you