Single Crystal Li-$Si_{1-x}Ge_x$ Bulk Semiconductor for Detector Applications

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ABSTRACT

Previous studies showed that single crystal, bulk grown Si_xGe_{1-x} crystals have a great potential for detection applications. The main advantage of Si_xGe_{1-x} based devices is improved absorption efficiency due to a high atomic number (Z) of Ge compared to Si. The bandgap of the compound semiconductor is somewhat smaller than the bandgap of silicon, but high enough to allow near room temperature operation.

The main challenge on the path toward implementation of such detectors is the low material resistivity. It is possible to increase the resistivity and to switch the material type from p to n by auto-compensation by lithium atoms. The diffusion and drift mechanisms of lithium are different in Cz and FZ grown materials. In addition, the presence of the germanium atoms affects the dynamics.

How Much *Ge* is Needed?

Ge%	Density [gr/cm^3]	E_{gap} [eV] **@90K**	Abs. @ 20 keV [cm^{-1}]	Abs. @ 50 keV [cm^{-1}]
0	2.328	1.16	9.9	0.89
5	2.5	1.15	21.9	1.78
10	2.67	1.12	33.6	2.67
20	3	1.075	57	4.41
100	5.327	0.72	223	16.8

SUMMARY & CONCLUSIONS

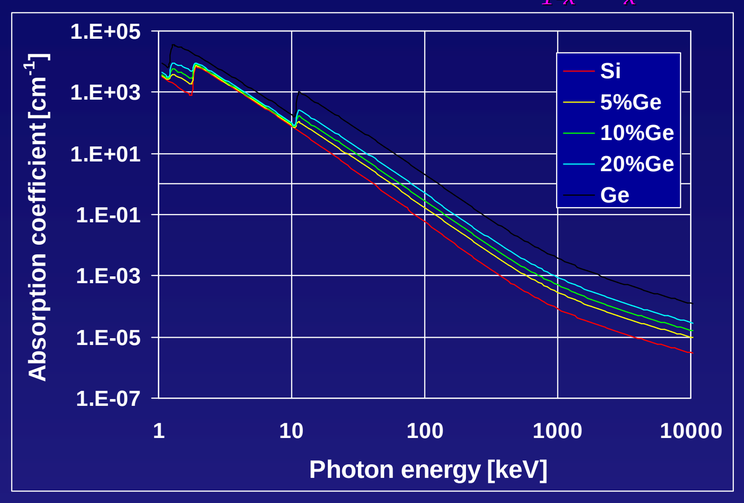
In this study we diffused lithium atoms into $Si_{1-x}Ge_x$ single crystals. The compound semiconductor was grown by Czochralski method and had high oxygen content. The results of lithium diffusion at 300C and 320C were investigated by SIMS and spreading resistance methods. Measurement of lithium content by SIMS is very challenging due to the low weight and the volatile nature of the element. The spreading resistance on the other hand provides information only about the electrically active fraction of lithium.

It was found that the diffusion is enhanced significantly by the presence of germanium atoms in the alloy. However, the diffusion is slower than in the float zone grown silicon as reported in literature (Si-Li detectors). This can be most likely attributed to the high content of oxygen, which reacts with lithium atoms.

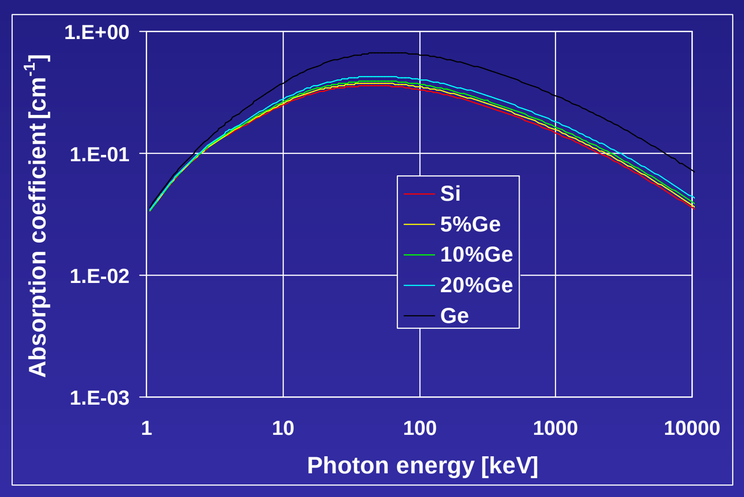
Partially drifted sample shows two doping regions: with and without compensation. From the slope of capacitance-voltage profile, it can be seen that the compensated resistivity is in the order of 1kΩ×cm.

Calculated Material Properties

Photoelectric Effect in $Si_{1-x}Ge_x$

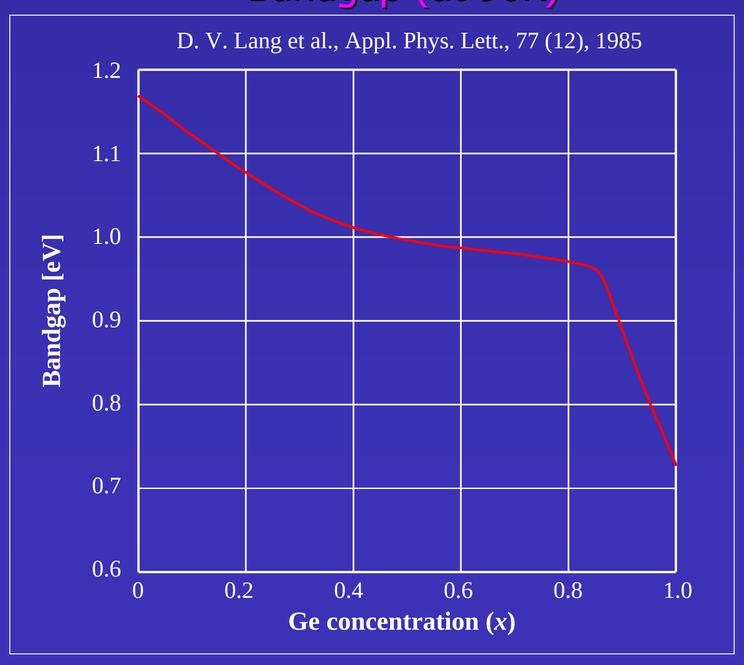


Compton Scattering in $Si_{1-x}Ge_x$



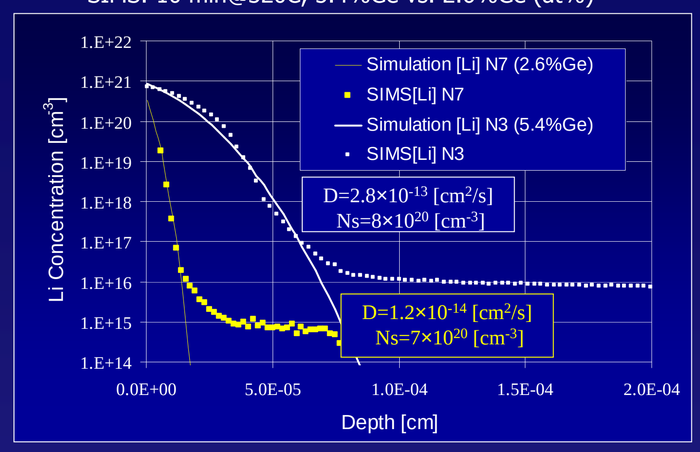
Bandgap (at 90K)

D. V. Lang et al., Appl. Phys. Lett., 77 (12), 1985

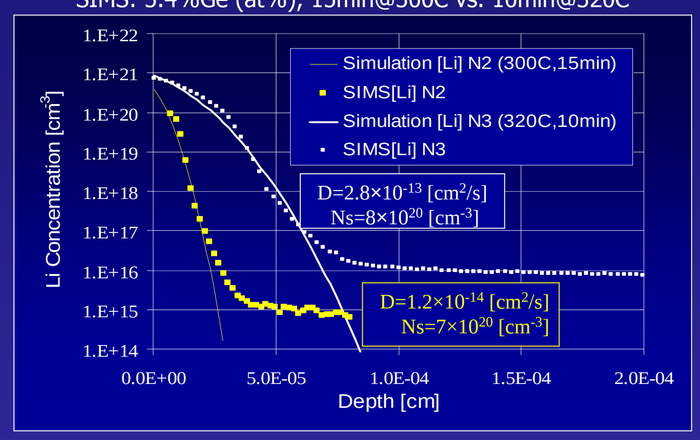


Lithium Diffusion Results

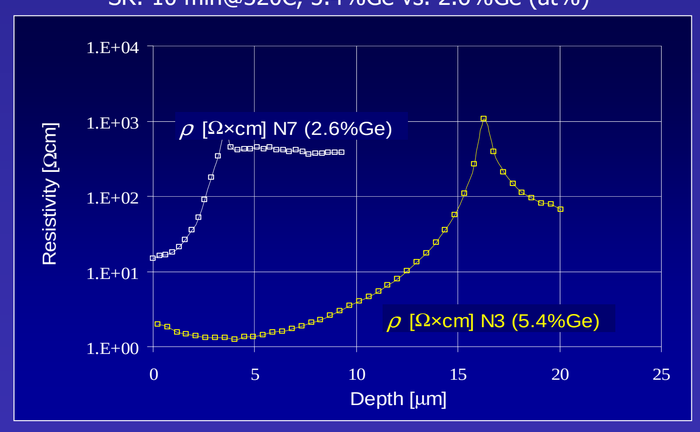
SIMS: 10 min@320C, 5.4%Ge vs. 2.6%Ge (at%)



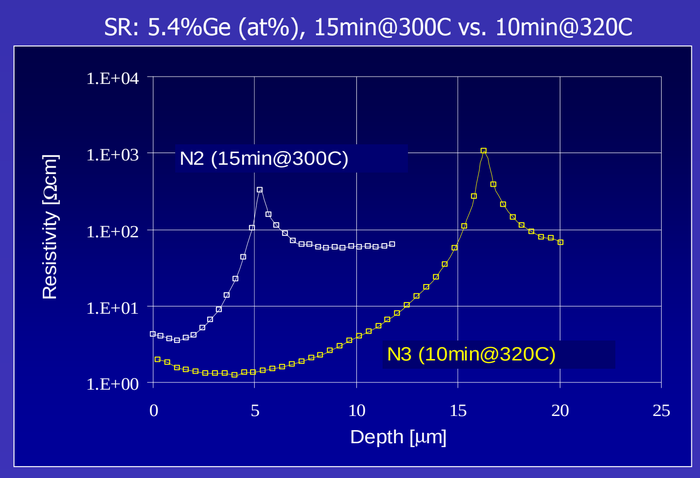
SIMS: 5.4%Ge (at%), 15min@300C vs. 10min@320C



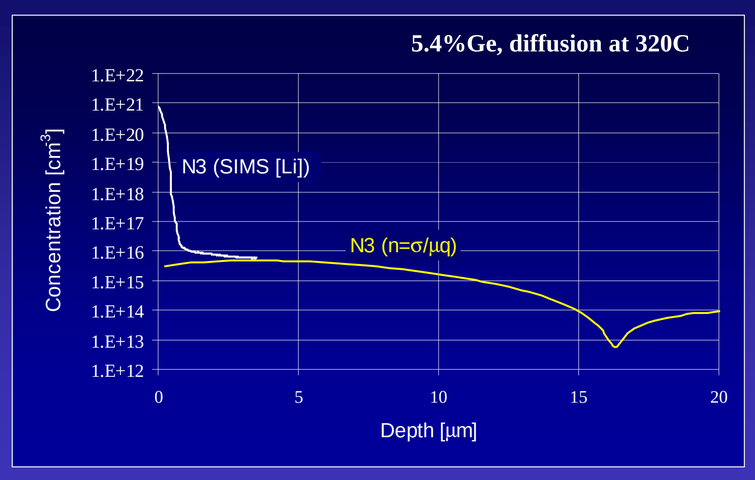
SR: 10 min@320C, 5.4%Ge vs. 2.6%Ge (at%)



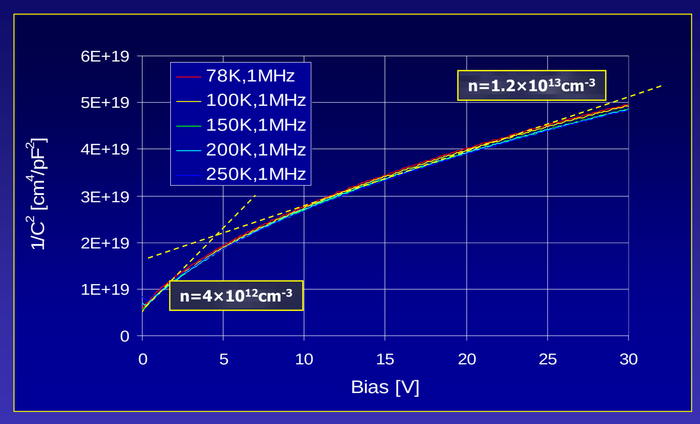
SR: 5.4%Ge (at%), 15min@300C vs. 10min@320C



Li concentration (SIMS) versus n deduced from ρ



1/C² and Temperature dependence



$$C = \sqrt{\frac{q\varepsilon N_{A,eff}}{2\left(V_{bi} + V_{Reverse} - 2kT/q\right)}} \Rightarrow \frac{1}{C^2} = \frac{2\left(V_{bi} + V_{Reverse} - 2kT/q\right)}{q\varepsilon N_{A,eff}}$$