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MOLECULAR BEAM EPITAXY OF $Al_xGa_{1-x}Sb$ AND $Al_xGa_{1-x}As$: NEW DONOR DOPING SOURCES*

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The first results obtained with the use of Ga_2S_3 and Ga_2Se_3 compounds as sources of donor elements for molecular beam epitaxy of $Al_xGa_{1-x}Sb$ ($0 \leq x \leq 1$) and $Al_xGa_{1-x}As$ ($0 \leq x \leq 0.4$) are reported. In GaAs free electron concentrations obtained when incorporating the donors from these sources can be easily controlled in the range of three orders of magnitude. For $Al_xGa_{1-x}Sb$ it was possible to compensate the high concentration of native acceptors and to obtain n-type of conductivity.

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Silicon and tin are commonly used as donor elements for doping of GaAs and AlGaAs grown by molecular beam epitaxy (MBE). However, for antimony based semiconductors grown by MBE the group IV elements were found to be amphoteric, which led to heavily compensated materials. Consequently, for successful n-type doping of antimonides group VI elements should be used. The main disadvantage of group VI elemental sources is the relatively high vapour pressure at the MBE baking-out temperatures. For the same reason it is very difficult to obtain easy-controllable low fluxes during the growth process. In order to reduce these negative effects there are some attempts to use compound sources [1] or electrochemical cells [2, 3].

In this study we report the first results obtained with the use of Ga_2S_3 and Ga_2Se_3 compounds as sources of donor elements for molecular beam epitaxy of $Al_xGa_{1-x}Sb$ ($0 \leq x \leq 1$) and $Al_xGa_{1-x}As$ ($0 \leq x \leq 0.4$). In GaAs the free electron concentrations obtained when incorporating the donors from the Ga_2S_3 and Ga_2Se_3 sources can be easily controlled in the range of three orders of magnitude reaching the top values of 6×10^{18} cm^{-3} and 3×10^{18} cm^{-3} for selenium and

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sulphur, respectively (see Fig. 1). In both cases the logarithms of the free electron concentrations depend linearly on the inverse source cell temperature with similar activation energies (1.7 eV for Se and 1.4 eV for S).

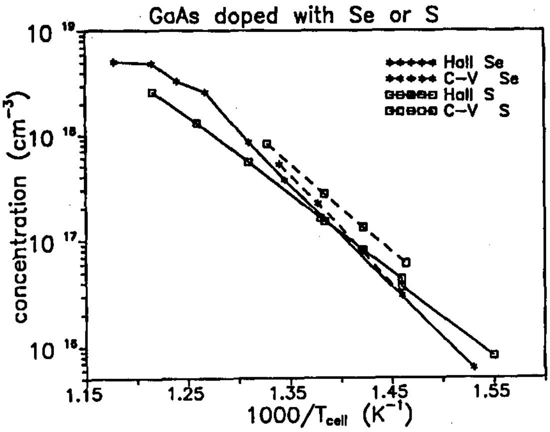

Fig. 1. GaAs n-type doping calibration curves for both sources. Dashed lines show the results obtained from the electrochemical profiler (C–V curves). Other results come from the Hall effect measurements.

The incorporation process of sulphur and selenium into GaAs layers seems to be very little sensitive to the substrate temperature in the temperature range between 500 and 600°C. For AlGaAs the growth temperature for a good quality layers must be much higher (approximately 670°C) than that for GaAs, but still one can get a doping level around 5×10^{17} cm^{-3}. The donor elements doping process was found to be very little sensitive to the III/V beam equivalent pressure ratio as well. This ratio has been varied between 1:5 to 1:50 and no systematic change in electron concentration has been observed. The latter finding indicates that the sticking coefficient is almost equal to unity for both dopants.

Undoped $Al_xGa_{1-x}Sb$ ($0 \leq x \leq 1$) layers grown by MBE at optimal conditions have p-type conductivity with the free hole concentration of $(5 \div 10) \times 10^{16}$ cm^{-3}, as a result of the high concentration of antimony vacancies. This value practically limits the lowest observable donor concentration in these materials. It was found that antimonides grown at standard temperatures and growth rates could not be successfully doped by using these sources. In order to get n-type of conductivity it was necessary to reduce the growth temperature below 500°C and the growth rate to 0.3 μm/h. At these conditions it was possible to obtain the n-type conductivity in the whole range of alloy compositions. The doping level has been checked by the Hall measurements for layers grown on SI GaAs substrates or by C–V profiling or deep level transient spectroscopy (DLTS) for layers grown on n^+-GaSb substrates with *in situ* prepared epitaxial aluminum Schottky diodes.

It is known from the previous studies [2] that in GaSb selenium atoms form shallow donor centres while sulphur has all features of the DX-type defect [3, 4]. In the GaSb:Se layer there is no electron freeze-out effect observed even at very low temperatures, while in the $Al_{0.12}Ga_{0.88}Sb$:Se layer at temperatures below 150 K there is a very distinct drop of electron concentration. In the DLTS spectra for this layer there is a new peak which is not observed for GaSb:Se. These observations suggest that for selenium atoms in GaSb the DX(Se) energy state is resonant with the conduction band (CB), while for AlGaSb the DX(Se) state emerges from CB to the band gap and can be observed in transport and DLTS experiments. The details of these results will be presented elsewhere.

The presented results show that the Ga_2S_3 and Ga_2Se_3 compounds are good doping sources for the MBE growth for both types of semiconducting crystals: $Al_xGa_{1-x}Sb$ and $Al_xGa_{1-x}As$. The existence of such universal sources is important for the MBE technology where usually separate sources for arsenides and antimonides had to be used.

References

[1] T.D. McLean, T.M. Kerr, D.I. Westwood, C.E.C. Wood, D.F. Howell, *J. Vac. Sci. Technol. B* 4, 601 (1986); T.H. Chiu, M. Ditzenberger, *Appl. Phys. Lett.* **56**, 1688 (1990).

[2] I.R. Cleverley, I. Poole, P.J. Cannard, K.E. Singer, in: *Inst. Phys. Conf. Ser.* No 112, Ed. K.E. Singer, IOP Publishing Ltd, Bristol 1990, p. 93.

[3] I. Poole, M.E. Lee, K.E. Singer, J.E.F. Frost, T.M. Kerr, C.E.C. Wood, D.A. Andrews, W.J.M. Rothwell, G.J. Davies, *J. Appl. Phys.* **63**, 395 (1988).

[4] L. Dobaczewski, P. Kaczor, J.M. Langer, A.R. Peaker, I. Poole, in: *20th Int. Conf. on Physics of Semiconductors*, Eds. E.M. Anastassakis, J.D. Joannopoulos, World Scientific, Singapore 1990, p. 497.