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Dependence of GaAs/AlGaAs Superlattice Ionization Rates on Al Content

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Effect of Al content (x) on GaAs/AlGaAs superlattice ionization rate was studied. The electron ionization rate is enhanced when the AlGaAs of the barrier is a direct transition type. It is drastically reduced by a Γ-X band crossover in the AlGaAs layer. At x=0.45, the excess multiplication noise is reduced to a value which corresponds to an ionization rate ratio of 0.14. It is increased by the band crossover.

Contradictory results have been reported for GaAs/AlGaAs superlattice ionization rates (α,β). Although it was reported that electron ionization rate (α) is enhanced[1], noise reduction of avalanche photodiodes (APDs) was not observed[2]. We have studied Al content dependence of GaAs/$Al_xGa_{1-x}As$ superlattice ionization rates. It was found that α is strongly influenced by a Γ-X band crossover of barriers, and that noise is reduced only when the barrier is a direct transition type. The experimental evidence of the noise reduction by superlattice structures was obtained for the first time.

The device is a p^+-i-n^+ structure. MBE grown non-doped superlattice (L_Z=450 A, L_B=550 A, 25 periods) were sandwiched by p^+- and n^+- GaAs layers. Four types of samples were prepared with x=0.3, 0.45, 0.55, and 0.65. It is expected that the effective band offset gets maximum at x=0.45 which is the critical point of the band crossover. A mesa structure with a diameter of 200μm was formed by chemical etching. Holes were etched in the substrate to illuminate n^+ layer.

The breakdown voltage, V_B, ranged from 73V to 85V which was the same range for the samples with all Al contents. The darkcurrent at $0.9V_B$ was smaller than 1nA and comparable with Si-APDs. The C-V measurement showed that the undoped superlattice region is already depleted by a built-in potential.

The ionization rates for samples with x=0.45 and 0.55 are shown in Fig.1 as a function of the reciprocal electric field. At x=0.45, α is significantly enhanced. On the other hand, α at x=0.55 is drastically reduced compared with that at 0.45.

Figure 2 shows the ionization rates at an electric field of 2.5×10^5 V/cm as a function of x. For the sample with x=0.45, which is thought to have the maximum effective band offset, α is enhanced and and becomes greater than bulk by a factor of 5. At x=0.3, α is also enhanced even if the band offset is small compared with x=0.45. Therefore, α increases as the conduction band offset is increased when the AlGaAs is a direct transition type. When x further increases and the barrier becomes an indirect transition type, α drastically decreases and bocomes comparable with bulk. On the other hand, β is almost independent of x.

Multiplication noise was measured for these four samples. Figure 3 shows the excess noise factor of samples x=0.45 and 0.55. The noise factor is remarkably reduced to a value which corresponds to ionization rate ratio (k_{eff}) of 0.14 at x=0.45. On the other hand, noise of x=0.55 sample fits to a theoretical curve of k_{eff}=0.8. The effective ionization rate ratio obtained by fitting theoretical curve to the measured excess noise factor is also plotted in Fig.2 as a function of x. The obtained ratio k_{eff} is consistent with the directly measured ionization rates.

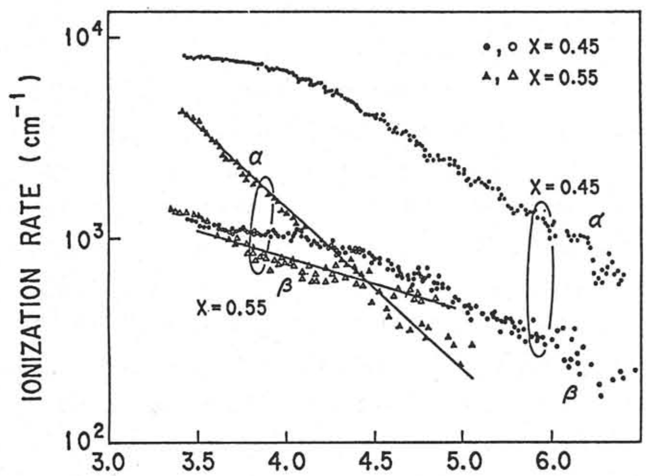

Fig.1 Ionization rates versus reciprocal electric field. Data are shown for samples with barrier Al content of 0.45 (circles) and 0.55 (triangles).

For indirect barrier samples, the majority of electrons are at the X valley of AlGaAs. It is thought the probability that they go to the GaAs X valley at the interface is large. Electrons cannot obtain kinetic energy through this process. This is the reason why α is refuced by the band crossover.

1) F.Capasso et al. APL 30(1982)38

2) N.Susa et al. JJAP 23(1984)317

3) G.E.Bulman et al. IEEE EDL-4 (1983)181

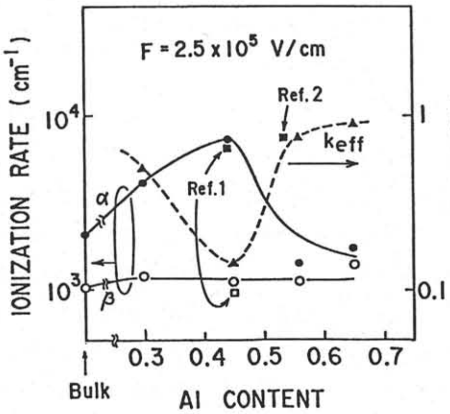

Fig.2 Dependence of ionization rates at an electric field of 2.5x10^5 V/cm on the barrier Al content. The effective ionization rate ratio k_{eff} obtained from excess noise factor is also shown. Data from Ref.1 and 2 are shown for comparison.

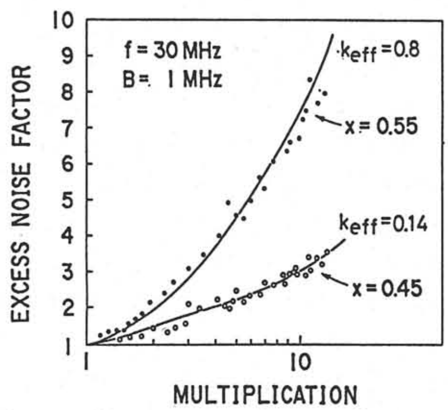

Fig.3 Excess noise factor of samples with x=0.45 and 0.55 versus multiplication factor. The solid lines are theoretical curve with ionization rate ratios of 0.14 and 0.8 following McIntyre's formula.