Indium Silicon Co-doping in AlGaN/GaN Multiple Quantum Wells

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Although AlGaN can emit much shorter wavelength light than InGaN, its emission intensity is normally much weaker. In this paper, we demonstrate that In and Si co-doping improves light emission intensity of AlGaN/GaN multiple quantum wells (MQW).

2 μm-thick GaN and AlGaN/GaN MQWs were grown sequentially by atmospheric pressure MOCVD at 1075 C on sapphire (0001) substrate. TMGa and TMAl flow rates were fixed, but the resultant Al composition was changed in the range of 12 to 17 % depending on the doping conditions. Silicon doping was done by flowing SiH_4 gas at a rate 440 μmol/min, which produced free electron concentration of about 5×10^{18} cm^{-3}. A fixed amount of TMIn (1.8 μmol/min) was flown during growth to dope indium. Although the growth temperature is quite high, In was detected by SIMS in the grown films. Undoped GaN, Mg-doped GaN and Si-doped GaN were also grown for comparison.

Sixteen different kinds of In-Si-Co-doped MQWs are possible depending on the layer to dope. Summaries of room temperature PL of the 250 period of MQWs and GaN are listed in Table 1. Doping Si or In into GaN improves PL intensity by a factor of 3 to 10. Doping Si in MWQ improves one order of magnitude, and further improvement is obtained by In co-doping. The strongest PL was obtained in (In-doped AlGaN/Si-In-doped GaN) MQW whose PL intensity is more than two orders of magnitude stronger than that of the undoped GaN.

Table 1 Summaries of room temperature PL measurement of 250 period MQWs and GaN

	In doping*	PL Intensity (arb. Units)	PL peak wavelength (nm)
u-GaN	u	0.003	362
(2 μm)	G	0.01	362
Si-GaN	u	0.04	363
(2 μm)	G	0.05	363
Mg-GaN	u	N/D	-
(2 μm)	G	N/D	-
(u-AlGaN/u-GaN)	u	0.05	344
(2 nm/2 nm)	G	0.07	344
(2 nm/2 nm)	A, G	0.11	345
(Si-AlGaN/u-GaN)	u	0.82	346
(2 nm/2 nm)	A, G	0.66	338
(Si-AlGaN/Si-GaN)	u	0.87	346
(2 nm/2 nm)	G	0.61	343
	A, G	0.54	338
(u-AlGaN/Si-GaN)	u	0.66	346
(2 nm/2 nm)	A	0.72	343
	G	0.74	347
	A, G	1	346

* u: undoped, G: doped in GaN, A: doped in AlGaN

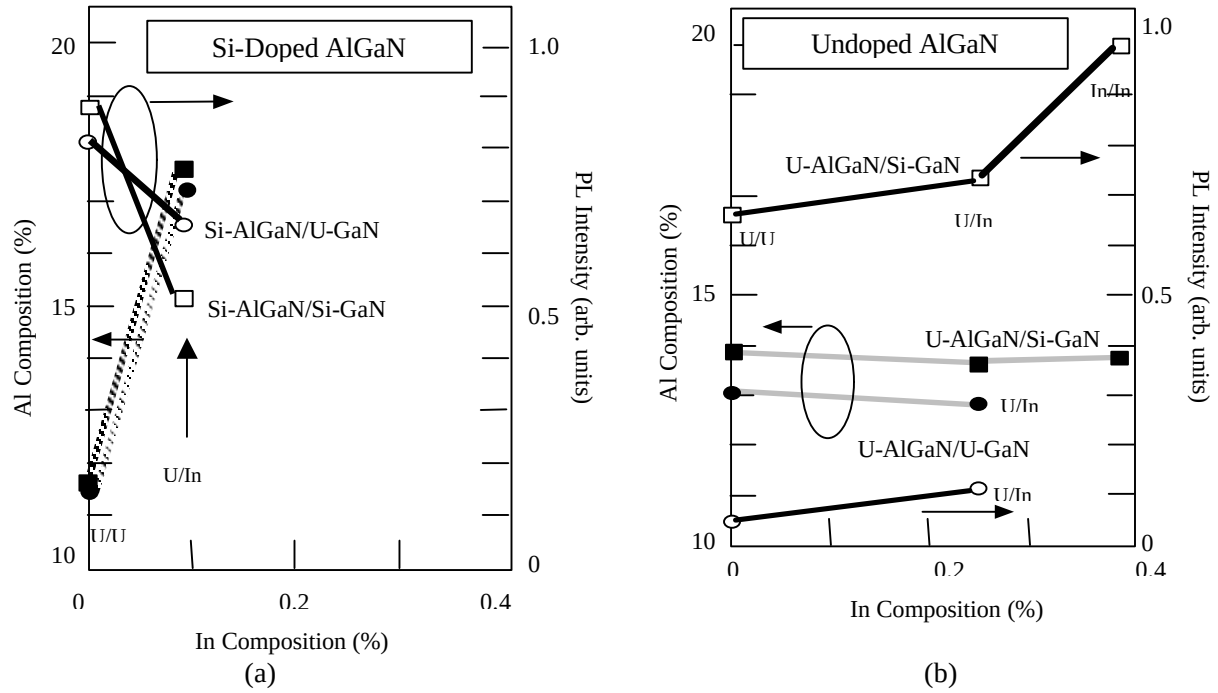

Fig.1 Averaged Al composition and PL intensity as a function of averaged In composition in 250 period AlGaN/GaN MQWs with Si-doped AlGaN (a) and undoped AlGaN (b), respectively. Averaged Al and In composition was measured by X-ray diffraction and SIMS, respectively. U/In, for example, indicates In-doped AlGaN/undoped GaN MQW.

Firstly, only In doping effect is discussed. Comparison of PL intensity of u-GaN (0.003), In-GaN (0.01), (u-AlGaN/u-GaN) (0.05) (u-AlGaN/In-GaN) (0.07) and (In-AlGaN/In-GaN) (0.11) indicates that the doping in GaN or AlGaN improves PL, where numbers in parenthesis indicate PL intensity. This suggests In doping decreases effective non-radiative recombination centers.

Secondly, effects of only Si doping can be summarized as that the doping into AlGaN than in GaN has more effect to improve PL. This is clear by the comparison of (u-AlGaN/u-GaN) (0.05), (Si-AlGaN/u-GaN) (0.82), (u-AlGaN/Si-GaN) (0.66), and (Si-AlGaN/Si-GaN) (0.87). Increased electron density may increase PL intensity, but Si seems to degrade GaN quality.

Lastly, Si-In-co-doping effects are summarized in Figure 1. It indicates that Si-In-co-doping into AlGaN increases Al composition and decreases PL intensity. However, only In doping in AlGaN or in GaN do not essentially change Al composition, and PL intensity increases with increasing In composition. Combining independent effects of In and Si doping, In doping both in AlGaN and GaN and Si doping only in AlGaN seems to be the best, however Si-In co-doping in AlGaN increases Al composition and degrades PL. As a second best combination, (In-AlGaN/In-Si-GaN) produces best PL.

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