

## Local Strain Relaxation by A-type Dislocation Clusters in In<sub>x</sub>Ga<sub>1-x</sub>N/GaN Film with Indium Compositions of x = 0.07 and 0.12

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A photovoltaic thermal hybrid solar cell is being developed for an energy conversion efficiency higher than the Shockley-Queisser limit, consisting of two junctions with different bandgaps operating on top of a thermal collector at 450° C under solar radiation focused by a concentrator. In<sub>x</sub>Ga<sub>1-x</sub>N thin films are used due to their wide bandgap range and their stability at high temperatures. The target compositions are x ~ 0.60 and 0.15. Good quality In<sub>x</sub>Ga<sub>1-x</sub>N layers with x ~0.60 has been achieved by molecular beam epitaxy.[1] This presentation deals with the microstructure of the lower indium content films. InGa<sub>N</sub> with 7% and 12% indium have been grown by metal organic vapor phase epitaxy. The early stages of misfit strain relaxation in this composition range appear as dislocation clusters that look like baskets.(Fig. 1) The nature of the basket defects has been studied under different diffraction contrast conditions. The threading dislocation surrounding the baskets have Burgers vectors lying on the basal plane, and therefore are not visible under  $g = 0002$ .(Fig. 2) The exact Burgers vectors are determined by large-angle convergent-beam electron diffraction (LACBED) in plan-view. The sample was tilted close to the [10-14] zone. The Bragg line intersecting a dislocation splits into several sections depending on the Burgers vector of the dislocation and on the nature of the Bragg line. Three LACBED images are recorded for each dislocation to completely determine the three independent components of the Burgers vector using Cherns and Preston rules.[2] The trace of the dislocation and the Burgers vector of each dislocation are labeled in Fig 3. These *a*-type dislocations appear in pairs with opposite Burgers vectors and are associated with a missing plane in the basket, contributing to the relaxation of the compressive misfit strain. The remaining strain in the basket can be calculated by counting the number of dislocations around a basket and taking the size of the basket into account:

$$\varepsilon = \frac{a_{\text{InGa}_N} - N/(N - n) \cdot a_{\text{Ga}_N}}{a_{\text{InGa}_N}}$$

and

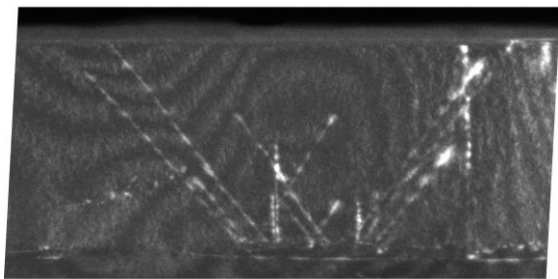
$$N = L/a_{\text{Ga}_N}$$

where *N* is the number of planes below the base of the basket; *L* is the lateral size of the basket base; *n* is the number of missing planes which is measured by counting dislocations in the basket from a plan-view TEM image (not shown here); *a*<sub>InGa<sub>N</sub></sub> and *a*<sub>Ga<sub>N</sub></sub> are the lattice parameters of InGa<sub>N</sub> and Ga<sub>N</sub>, respectively. The remaining strain is compared with the misfit strain and the degree of strain relaxation is concluded for each film. (Table. 1)

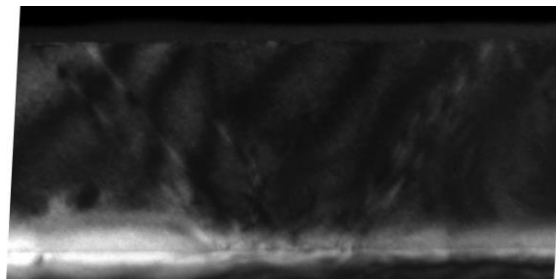
References:

[1] A. M. Fischer et al, *Appl. Phys. Lett.* **103** (2013), p. 131101.

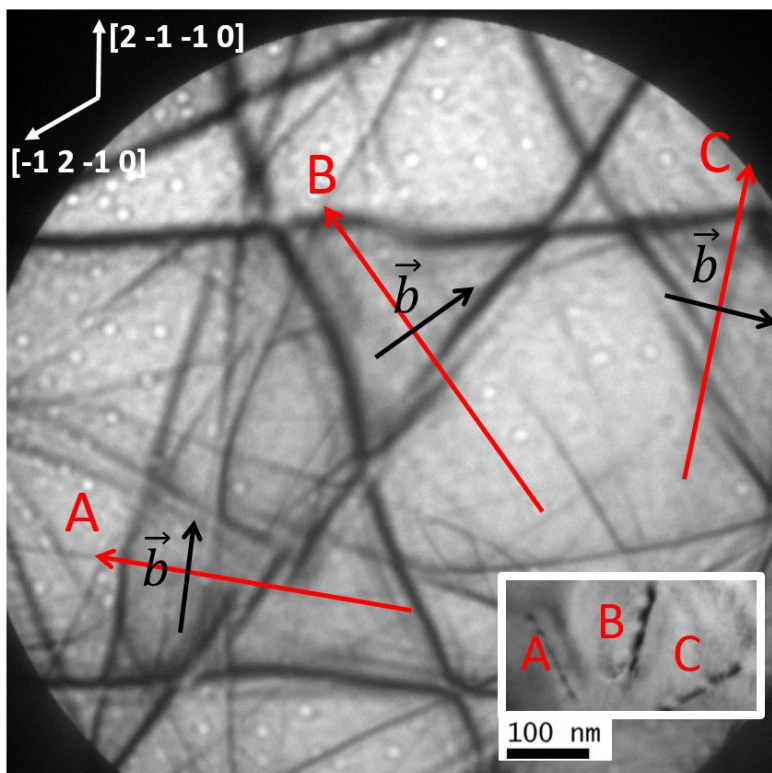
[2] D. Cherns and A. R. Preston, *J Electron Micr. Tech.* **13** (1989), p. 111.



**Figure 1.** Cross-section TEM of a basket, taken with  $g = 11-20$



**Figure 2.** Cross-section TEM of the basket in Fig. 1, taken with  $g = 0002$



**Figure 3.** LACBED image showing splitting of HOLZ Bragg lines at dislocation intersections. The inset shows the dislocations in a plan-view diffraction contrast image. The magnitude and direction of the Burgers vector is found to be  $1/3 \langle 11-20 \rangle$ .

Indium content	7%	12%
Misfit strain	0.77%	1.3%
Basket size	160 nm	200 nm
No. missing planes	0.8 in each $\langle 11-20 \rangle$	5 in each $\langle 11-20 \rangle$
Remaining strain	0.60%	0.52%
Degree of relaxation	~10%	~60%

**Table 1.** Local strain relaxation by the dislocation clusters in 7% and 12% InGaN film.