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CuPt-Type Ordering of MOCVD $In_{0.49}Al_{0.51}P$

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CuPt-type ordering in $In_{0.49}Al_{0.51}P$ is studied by TEM. The lattice-matched film was grown by MOCVD on a GaAs substrate oriented 10° off (001) towards [110], at 650°C and 25 nm/min. TEM [110] and $[1\bar{1}0]$ cross-sections (XS) were made by wedge polishing and 2 kV Ar ion milling.

In CuPt-type ordering of $In_{0.52}Ga_{0.48}P$, alternating In-Ga-In-Ga {111} planes of group III atoms produce $\frac{1}{2}\bar{1}11$ and $\frac{1}{2}1\bar{1}1$ order spots in the 110 SADP, while the $[1\bar{1}0]$ SADP shows no order spots [1-3]. A few studies have reported this type of order in $In_{0.49}Al_{0.51}P$ [4].

The 004 BF image of the $[1\bar{1}0]$ XS in Fig. 1 shows uneven light/dark contrast modulation due to phase separation often observed in $In_{0.52}Ga_{0.48}P$. There are also light/dark layers marked ML parallel to the film growth plane; such unintentional multilayers have also been observed [5] but their origin is not understood. Order lamellae ~1.5 nm thick inclined at a shallow angle to the growth plane overlap the multilayer to produce Moiré fringe contrast. Fig. 2 is a DF image showing the thin ordered domains in the $[1\bar{1}0]$ XS, which are inclined at 12° to the growth plane and 2° to (001). Fig. 3a shows the absence of order spots in the $[1\bar{1}0]$ SADP, while tilting 26.6° to $[3\bar{1}0]$ reveals rows of order spots characteristic of CuPt ordering (Fig. 3b). The fact that the domains lie within ~2° of (001) shows that their orientation is crystallographically determined, while the fact that the "multilayer" is parallel to the growth plane rather than to (001) shows that it is not crystallographically determined. Most work does not describe domains in the $[1\bar{1}0]$ XS, but Bellon et al. [1] commented that in a $[1\bar{1}0]$ XS their $In_{0.52}Ga_{0.48}P$ domains were exactly on (001) in a wafer 6° off (001) towards [110], consistent with our results. The domains and streaked order spots in our $[1\bar{1}0]$ XS show no significant deviation from (001), but one set of spots is slightly tilted.

Fig. 4 shows $\frac{1}{2}\bar{1}11$ and $\frac{1}{2}1\bar{1}1$ order spots in the SADP of the [110] XS, and Fig. 5 shows DF images taken with order spots from the two variants. The total ordered volume appears to be less than 100%. The domains generally appear parallel to (001), but closer examination shows that many are inclined ~ 10° clockwise from (001) in Fig. 5a, while a few are inclined counterclockwise in Fig. 5b. The streaks centered at $\frac{1}{2}\bar{1}11$ and $\frac{1}{2}1\bar{1}1$ are rotated ~±9° from [001]. The wavy lines in [110] SADPs were explained by Baxter et al. [2], who showed that antiphase domains (APDs) of the two variants inclined several degrees in opposite directions from (001) in the [110] XS produced inclined streaks normal to the APDs at the $\left\langle\frac{1}{2}\frac{1}{2}\frac{1}{2}\right\rangle$ positions. Each APD was made up of alternating (001) platelets of the two variants, about 0.6-2 nm thick and ~800 nm wide producing the streaking along [001]. At lower growth temperatures the APDs are much thinner [2] and Yang et al. [3] showed that domains become almost rod-like. Our domains are relatively narrow, ~10-40 nm wide, and 1.5 nm thick (Figs. 5,6) and the lengths of the inclined streaks in Fig. 4 are approximately correct for 1.5 nm thick plates. The general lack of inclination of individual domains, especially in Fig. 6, seems inconsistent with the streak inclinations in the SADP. This could be due to undetected inclined APBs within the domains. [6]

References

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[6] This work was supported by AFOSR. TEM work at Argonne National Laboratory was supported by the U. S. DOE, Office of Science, under Contract W-31-109-Eng-38.

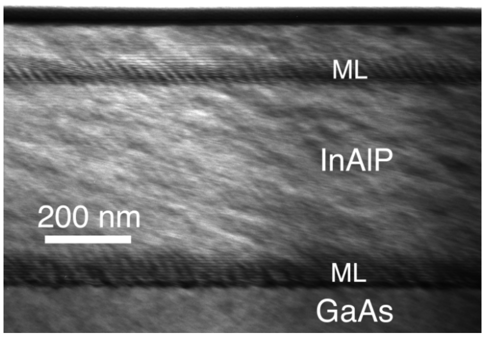

Fig. 1. 004 BF image of $[1\bar{1}0]$.

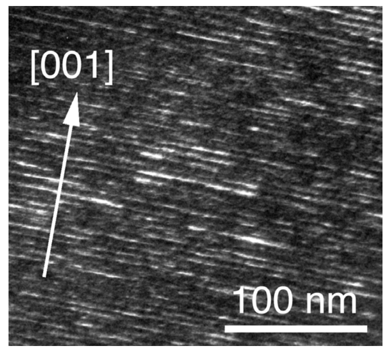

Fig. 2. DF image of domains in Fig. 1.

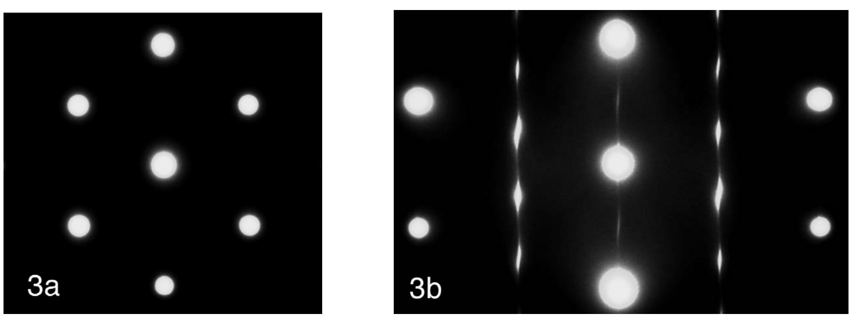

Fig. 3. SADPs of $[1\bar{1}0]$ XS.
a) $[1\bar{1}0]$;
b) $[3\bar{1}0]$

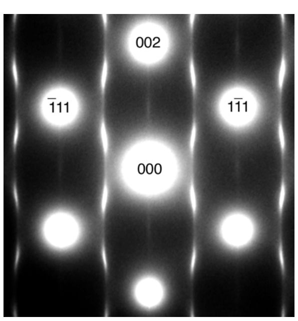

Fig. 4 [110] SADP.

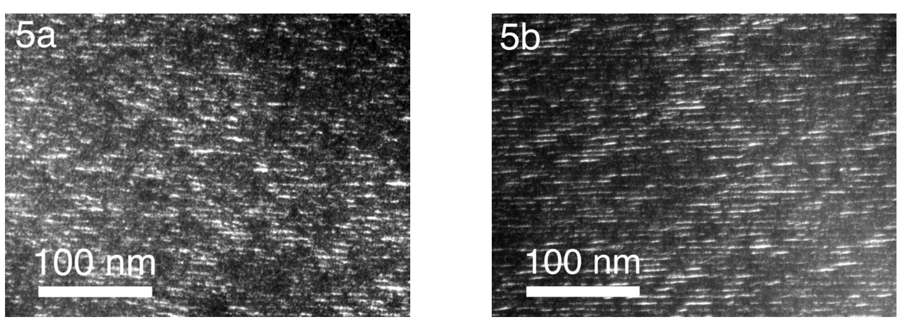

Fig. 5. Domains in [110] XS. a) $\frac{1}{2}1\bar{1}1$ DF image; b) $\frac{1}{2}\bar{1}11$ DF image.

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