Reducing bow of InGaP on silicon wafers

Researchers use strain engineering without impacting dislocation density.

Researchers based in Singapore and the USA have been working to control the wafer bow of indium gallium phosphide (InGaP) epitaxial layers on 200mm silicon (Si) wafers [Bing Wang et al, Semicond. Sci. Technol., vol32, p125013, 2017].

Wafer bow is caused by stress arising mainly from mismatches of coefficients of thermal expansion between InGaP, or other III-V compound semiconductors, and silicon. The bow (more than 200μm in one recent report of gallium arsenide on 300mm silicon wafer) is introduced when the material cools after high-temperature epitaxial deposition. Bowing adversely affects wafer-scale processing, particularly for large-diameter substrates. Wafer-scale equipment typically restricts the permitted bow to less than 50μm.

The team from the Singapore–MIT Alliance for Research and Technology, Nanyang Technological University in Singapore, and Massachusetts Institute of Technology in the USA used strain engineering to reduce bow in InGaP templates grown on high-quality germanium (Ge) buffers on silicon.

The 200mm (8”) silicon substrate was offcut 6º toward the nearest {111} plane. Epitaxy was by metal-organic chemical vapor deposition (MOCVD). The germanium on silicon template layer was prepared separately in a two-step low/high-temperature process, using germane (GeH_4) precursor. Plan-view transmission electron microscopy (PV-TEM) and etch pit density (EPD) analysis gave an estimate of dislocation density of the order $3x10^7/cm^2$.

The MOCVD reactor was thoroughly cleaned to remove Ge residues before III-V epitaxy (Figure 1), avoiding uncontrollable n-type doping. The group-III metal-organic precursors were trimethyl-gallium and

“Based on these observations, we can conclude that the threading dislocation densities of the InGaP wafers are not affected by the lattice mismatch. Our Ge buffers have similar threading dislocation density of $3x10^7/cm^2$. The hetero-epitaxy of GaAs buffers and InGaP films did not increase the threading dislocation density, which indicates very good epitaxy quality.” The team believes that the technique can be applied to other III-V systems on silicon

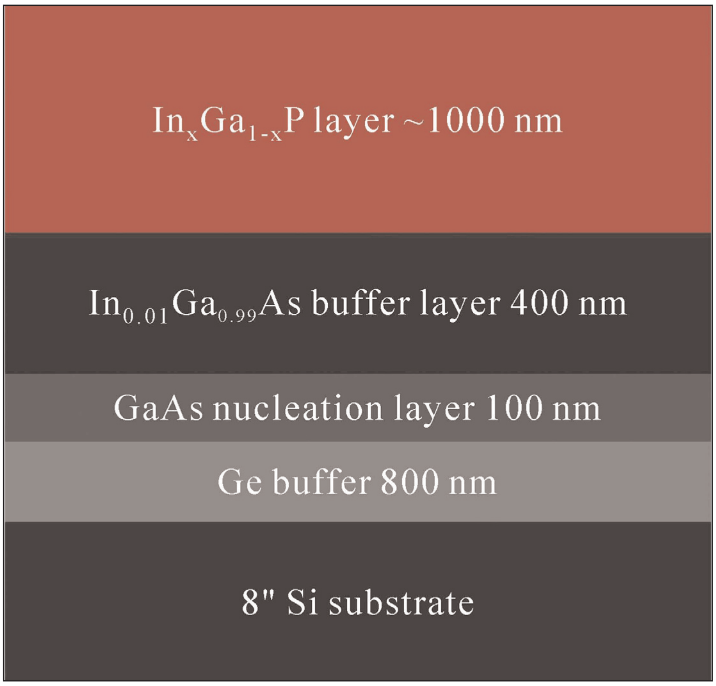

Figure 1. Epitaxial layer structure of three InGaP/Si wafers.

Table 1. Summary of InGaP sample compositions, wafer bow, strain, relaxation, and threading dislocation densities (EPD and PV-TEM).

Sample $In_xGa_{1-x}P$	Wafer bow	Strain	Relaxation	EPD ($x10^7/cm^2$)	PVTEM ($x10^7/cm^2$)
x = 0.49	−82.5μm (110)	0.251%	−37%	1.5	3.1
	−97μm (1−10)	0.222%	29%		
x = 0.54	−11μm (110)	−0.054%	17.5%	1.6	2.8
	−32.7μm (1−10)	−0.041%	25.5%		
x = 0.52	−27.7μm (110)	0.012%	−0.9%	1.7	1.9
	−44.2μm (1−10)	−0.003%	1.5%		

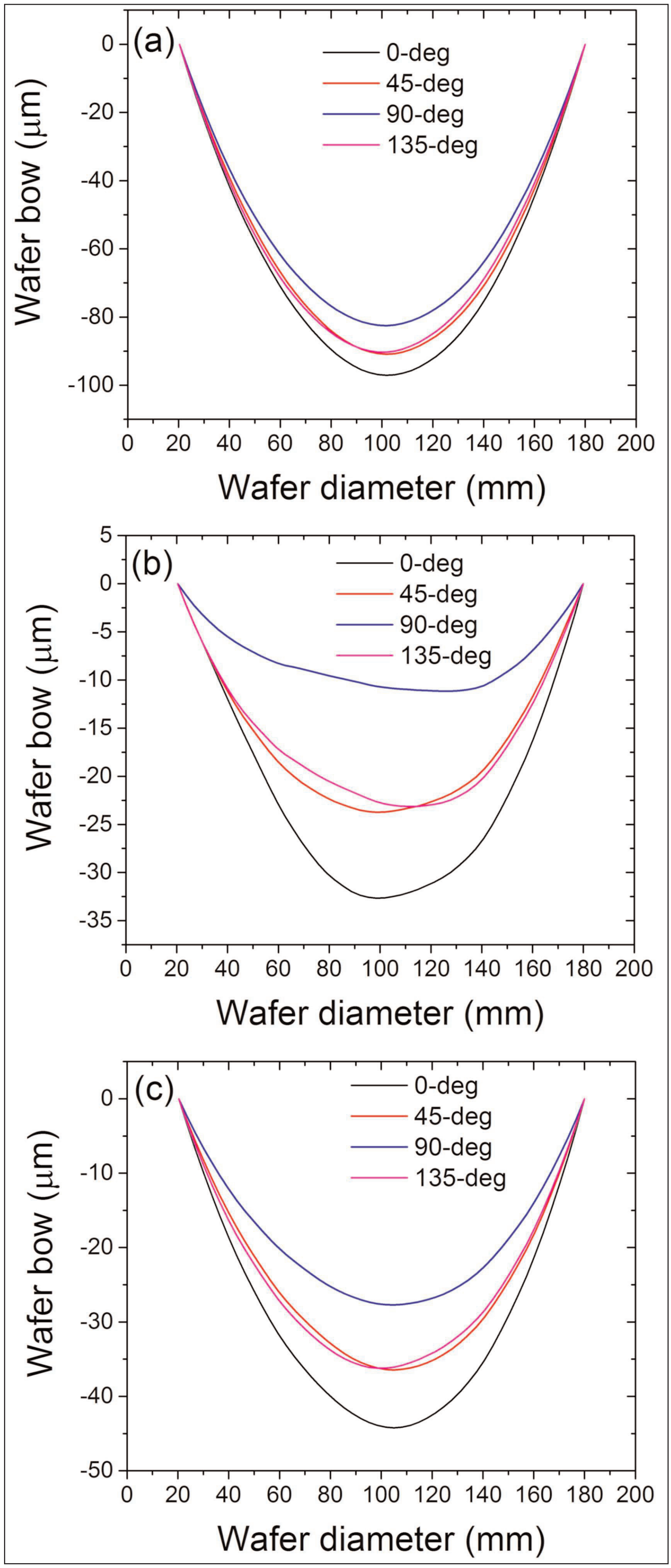

Figure 2. Wafer bow of InGaP wafers: x = 0.49 (a), x = 0.54 (b), and x = 0.52 (c). Wafer notch orientation (1–10) is 0º, and (110) direction is 90º.

trimethyl-indium. The group-V arsenic (As) and phosphorus (P) components were delivered by arsine (AsH_3) and phosphine (PH_3), respectively. Hydrogen was the carrier gas.

The 1%-indium-content InGaAs formed the main part of the buffer since its lattice mismatch with Ge was smaller than that of pure GaAs. Three InGaP compositions were produced: lattice-matched with 49% indium content, along with non-matched 52% and 54% samples. The MOCVD temperature was 630ºC, with less than 10ºC variation across the wafer.

Atomic force microscopy showed increasing roughness as the InGaP became more mismatched — 1.68nm root-mean-square for $In_{0.49}Ga_{0.51}P$, 2.08nm for $In_{0.52}Ga_{0.48}P$ and 2.34nm for $In_{0.54}Ga_{0.46}P$. The roughness of the GaAs buffer was 0.8nm. The wafers exhibited anisotropic concave bows of up to 97μm (Figure 2). The bow was greatest for the $In_{0.49}Ga_{0.51}P$, decreasing with increase in indium content.

X-ray reciprocal space map analysis was used to assess strain in the resulting wafers (Table 1). The lattice-matched $In_{0.49}Ga_{0.51}P$ wafer was observed to have a tensile strain and the $In_{0.49}Ga_{0.51}P$ sample was under compression. The middle $In_{0.52}Ga_{0.48}P$ material was slightly tensile strained (0.01%) along the (110) direction and compressed (–0.003%) along the $(1\bar{1}0)$ direction.

The researchers point out that dislocation mobility is anisotropic, commenting "anisotropic strain and relaxation correlate with the anisotropic wafer bow very clearly." They add: "compensation of the thermal stress by the lattice-mismatch strain decreases the wafer bow."

The threading dislocation density (TDD) of the InGaP layers was about the same at $1.6x10^7/cm^2$, according to EPD analysis. PV-TEM gave an estimate of $3.1x10^7/cm^2$ for the $In_{0.49}Ga_{0.51}P$ wafer.

The researchers comment: "Based on these observations, we can conclude that the TDDs of the InGaP wafers are not affected by the lattice mismatch. Our Ge buffers have similar TDD of $3x10^7/cm^2$. The hetero-epitaxy of GaAs buffers and InGaP films did not increase the TDD, which indicates very good epitaxy quality." The team believes that the technique can be applied to other III-V systems on silicon. ■

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