Although nickel has long been used as a contact material to InGaAs, details of low temperature phase formation are not perfectly explored yet. In a recent publication formation of a single Ni$_4$In$_2$GaAs$_2$ phase with hexagonal structure was described and epitaxial growth to the InGaAs substrate at 250°C was claimed [1]. We confirm the formation of the hexagonal structure here, however we report on the formation of a polycrystalline Ni$_6$In$_2$GaAs$_2$ reaction layer at 350°C.

A 300 nm thick lattice matched p-(In$_{0.53}$Ga$_{0.47}$)As layer was grown epitaxially on InP substrate. 20 nm Ni was deposited on it and covered with 7 nm TiN protecting film. The samples were RTP annealed for 60 s at 350°C in nitrogen atmosphere to induce the solid state reaction between Ni thin film and the InGaAs layer. The reaction product was studied by Auger Electron Spectroscopy (AES) depth profiling, cross sectional TEM and Atom Probe Tomography (APT). The AES analysis used 5 keV primary electron energy, 20 nA beam current with a diameter of 40 µm. For the depth profiling Ar$^+$ ions of 1 keV energy were applied and the angle of incidence with respect to the surface normal was 80°. All specimens were rotated during sputtering. The Ar pressure was 2.5*10$^{-7}$ torr. The TEM lamellae were prepared by Ar$^+$-ion milling (10 keV, 2 mA) till perforation, followed by 2 keV ion milling to remove damaged layer. Both BF and HRTEM images and selected area electron diffraction patterns were recorded in a JEOL 3010, operated at 300 keV. The GATAN camera in the GIF Tridiem was used for imaging and a GATAN Orius camera in the JEOL 3010 recorded the diffraction patterns. Fast Fourier transforms (FFT) of the HRTEM images were also analyzed identically to diffraction patterns.

The reaction layer is about 55-60 nm thick polycrystalline film (Fig 1). Its composition is close to Ni$_6$In$_2$GaAs$_2$, as measured by AES. The same composition was also determined by APT. Examining both the individual grains one-by-one in the HRTEM image and of the FFTs from different grains in that HRTEM, we see that the growth is not epitaxial in general, since all grains have different orientations. As an example, a HRTEM image including 3 grains and the FFT for one of the grains indexed with the ProcessDiffraction program [2] are shown in Fig. 3 and Fig.4, respectively. For the indexing we used the hexagonal structure published in [1] but allowed for a mall tolerance in the measured d-values, because our XRD measurements showed that the measured diffraction lines were slightly shifted from the values reported in the literature. The small change in the lattice parameters may be connected to the different composition.


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Fig. 1: Polycrystalline reaction layer. The interface to the InGaAs is close to planar at large scale however, non-perfect planarity is obvious from the undulations following grains at the bottom interface. Layer thickness is 55 nm±10 nm.

Fig. 2: AES depth profile of the in-depth distribution of elements in the reaction layer. It is seen that the composition is almost constant along the depth of the layer and it is close to NiInGaAs₂, a value also measured with APT.

Fig. 3: HRTEM image with 3 grains of the reaction product layer all differently oriented. All 3 grains were successfully indexed as hexagonal NiInGaAs₂ phase allowing for a small tolerance in the d-values.

Fig. 4: Central part of the FFT from the middle grain (Grain2) in Fig. 3. Indexed as NiInGaAs₂ allowing for a small tolerance in the d-values. Successful indexing of several such patterns from different orientations indicate that the crystal structure must be the one published in [1] with slightly different lattice parameters.