Metamorphic InAs 2DEGs for quantum computation platforms

D. Curcio[1*], O. Batchuluun[1,2], L. Sbuelz[1], S. K. Appani[1,] M. Kirti[1,2], M. Sütő[4], E. Tóvári[3], P. Makk[3], T. Prok[3], S. Csonka[3], G. Biasiol[1]
[1]CNR - Istituto Officina dei Materiali (IOM), 34149 Trieste, Italy
[2]Department of Physics, University of Trieste, 34128 Trieste, Italy
[3]Department of Physics, Budapest University of Technology and Economics and Nanoelectronics "Momentum" Research Group of the Hungarian Academy of Sciences, 1111 Budapest, Hungary
[4] HUN-REN Centre for Energy Research, Institute of Technical Physics and Materials Science, 1121 Budapest, Konkoly Thege Miklós út 29-33.

* curcio@iom.cnr.it

The development of quantum computing still relies on the development of advanced material platforms. Among the most promising candidates are semiconductor-superconductor hybrid systems, such as Andreev quantum bits and Kitaev transmons. These systems are based on high-quality superconducting thin films with transparent interfaces to low-dimensional semiconductors, offering the potential for extended coherence times and robust qubit-qubit coupling [1].

To this end, a metamorphic growth protocol has been employed, and low-temperature electron mobilities up to 8×10^5cm^2/Vs have been achieved in undoped deep InAs/$In_{0.81}Ga_{0.19}As$ two-dimensional electron gases (2DEGs) grown on GaAs (001) [2]. Additionally, superconducting proximity effects have been observed in Josephson junctions between shallow InAs 2DEGs and epitaxial Al layers [3]. Optimal mobilities were achieved by tuning the thickness t of a strain-relieving $In_{0.84}Al_{0.16}As$ layer beneath the quantum well (QW) region [2].

Here, discuss the strain relaxation dynamics for varying t and their impact on electron scattering mechanisms in the InAs 2DEGs. Two-dimensional XRD reciprocal space maps of the (004) and (224) reflections (Fig. 1) reveal how increasing t from 50 nm to 300 nm leads to near-complete strain relaxation and a reduction in mosaicity in both the InAs QW and the surrounding barriers. Mobility measurements from gated Hall bars (Fig. 2) reveal striking gains in electron mobility and a reduced anisotropy between the [110] and [-110] orientations as t grows. This improvement stems from diminished anisotropic scattering mechanisms, linked to the cross-hatch roughness pattern—a memory of the buried dislocation network in the buffer layer (see insets of Fig. 2). These features, shaped by strain and composition fluctuations, highlight the interplay between structural engineering and electronic properties.

[1] J. S. Lee et al. Nano Lett. **19**, 3083 (2019)
[2] A. Benali et al., J. Cryst. Growth **593**, 1267681 (2022)
[3] M. Sütő et al. Phys. Rev. B **106**, 235404 (2022)

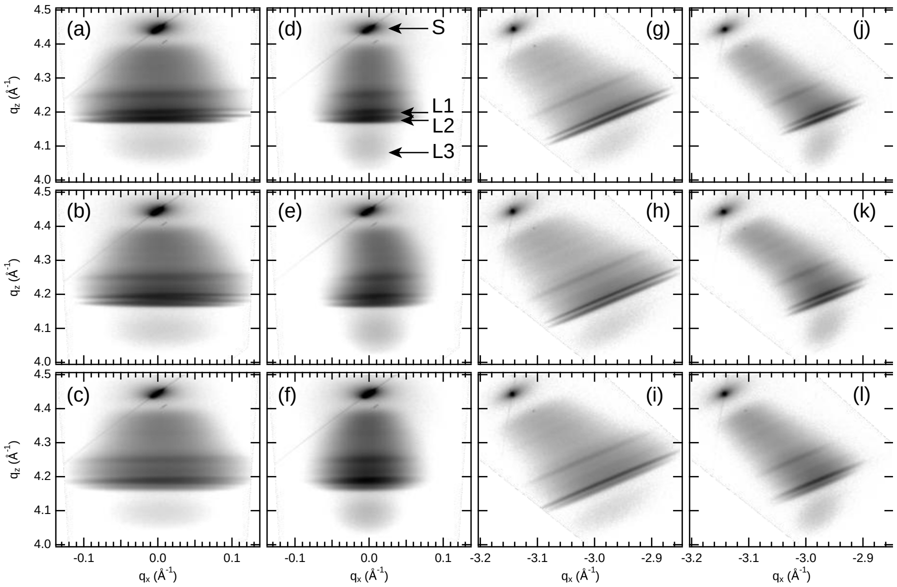

Fig. 11: X ray diffraction reciprocal space maps of (004) (a-f) and (224) reflections (g-l) of InAs QWs along the [110] direction (a-c, g-i) and along the [-110] direction (d-f, j-l) with t = 300 nm (a,d,g,j) , 150 nm, (b,e,h,k) and 50 nm (c,f,I,l).

Substrate, In$_{0.81}$Al$_{0.19}$As, In$_{0.84}$Al$_{0.16}$As, and InAs peaks are labelled as S, L1, L2 and L3, respectively.

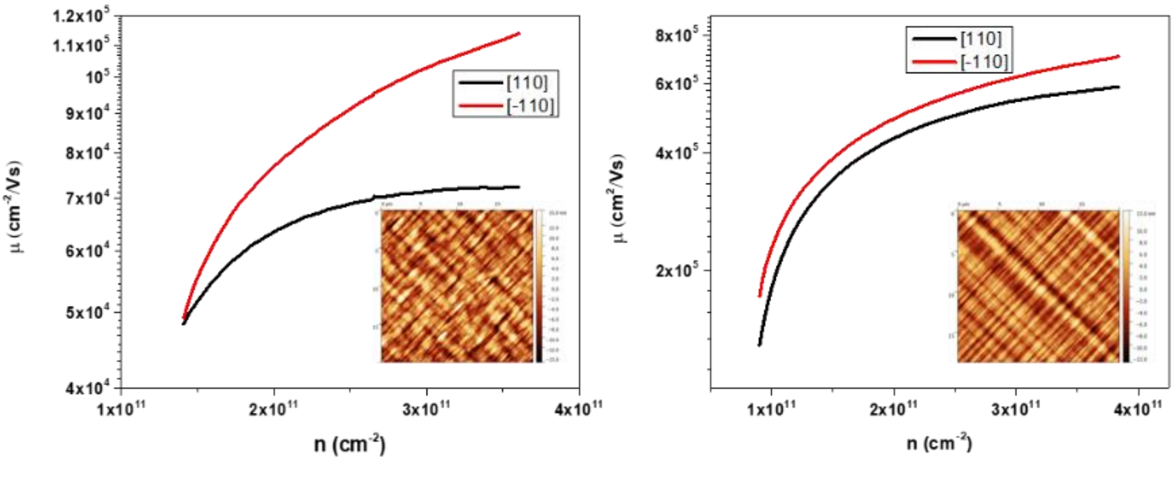

Fig. 22: Mobility vs. charge density along [110] and [-110] for t = 50nm (left) and 300nm (right). Inset: corresponding AFM images of top surfaces.