Advanced STEM Characterisation of SiGe/Ge Quantum Wells for Quantum Computing

Marc Botifoll[a]
Carla Borja[b], Sara Martí-Sánchez[a], Daniel Jirovec[b], Kushagra Aggarwal[b], Georgios Katsaros[b], Jordi Arbiol[a,c]

a. Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Barcelona, Catalonia, Spain
b. Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria
c. ICREA, Pg. Lluis Companys 23, 08010 Barcelona, Catalonia, Spain

marc.botifoll@icn2.cat

Quantum computing is thought to be one of the main technological revolutions to occur in the current century. It will become ubiquitous in our society providing with powerful tools to solve scientific problems in diverse fields such as chemistry and drug design, biomedical research and personalised medicine, and engineering, among others. Towards achieving quantum processing units, germanium is an outstanding platform to create well-controlled quantum dots given its high hole mobility and low effective mass. In this study, we have explored the materials science implications behind the creation of a Ge-based Josephson field-effect transistor (JoFET) [1] and a singlet-triplet hole spin qubit [2].

We proceeded with a complete electron microscopy-based study to correlate the quantum performance of the devices with their crystalline quality. HAADF-STEM was used to get atomic resolution micrographs of the misfit dislocation-free Ge quantum wells (QW) and their interfaces with the SiGe surrounding layers, and crystalline Al and Nb metallic contacts, when present. We computed the elastic strain by a correlative study between geometrical phase analysis (GPA) and quantitative-EELS and X-ray diffraction (XRD). We proved the feasibility of extracting reliable quantitative compositional information by means of core-loss EELS despite plural scattering when complementary reference values are provided (e.g. XRD). We used this precise compositional information to correlate the relative lattice displacements unveiled by GPA to the strain to which every region of the device has undergone.

In conclusion, we have applied a systematic structural-compositional correlative characterisation to state-of-the-art Ge-based devices for hole spin qubits generation in an ongoing study aiming for an optimised quantum performance.

References

[1] Aggarwal, K et al, *Physical Review Research*, **3**(2), (2021) L022005
[2] Jirovec, D. et al. *Nature Materials*, (2021) doi.org/10.1038/s41563-021-01022-2

Figures

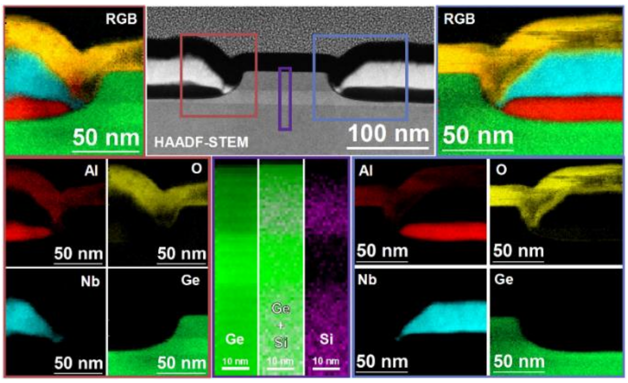

Figure 1: Electron Energy-Loss Spectroscopy (EELS) compositional maps of the JoFET device and its germanium quantum well and surrounding Al-Nb contacts. The EELS maps were taken at 200kV, with a spatial resolution of around 1nm.