# CVD graphene on Ge substrate: how properties are tuned by growth and annealing temperature

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Graphene integration in solid state device technology able to exploit the many unique graphene properties and transformational opportunities needs CMOS-compatible metal-free graphene film [1]. Thanks to the catalytic activity of Ge on carbon precursors combined with Ge carbides instability and low C solubility, graphene grown by chemical vapor deposition (CVD) on Ge appears as one of the most promising routes for this goal [2].
The data reported in literature reveal a challenging scenario for the graphene/Ge interface properties in terms of a complex interplay between the graphene quality and Ge morphology modification produced by graphene growth, depending for example on Ge surface orientation, hydrogen presence, growth and annealing temperature. In our work we investigated the structural and electronic properties of CVD graphene/Ge system as a function of deposition and annealing temperature by combining Raman, XPS, ARPES, AFM and STM techniques. We established a correlation between structural changes occurring at the atomic scale in graphene and the nanoscale morphology of Ge(001) and Ge(110) oriented surfaces [3-6]. We find that, close to the Ge melting point, small variations in the deposition temperature dramatically affect the quality of the graphene adlayer. By decreasing the growth from 930 °C to 910 °C we observe an evolution from a flat and almost defect-free graphene layer to a more wrinkled and defective graphene. The abruptness of the temperature behavior observed can be consistently explained by the incomplete surface-melting behavior of Ge and indicates that the quasi-liquid Ge layer formed close to 930 °C is fundamental to obtain high-quality graphene. The enhanced mobility of Ge atoms in the surface-melting regime can explain the nucleation of a second graphene layer in a layer-by-layer regime we established at high growth temperature, in contrast to the self-limited graphene growth observed at lower temperatures when the Ge surface is solid.
Moreover we proved that post-growth annealing can tune the interface properties of the system in terms of doping and Ge surface reconstruction, and significantly are able to restore high quality graphene by healing the defects induced by hydrogen desorption [7,8].

**References**

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