Group-IV $Ge_{1-x}Sn_x$ alloys: growth challenge and isothermal heteroepitaxy for electronic, photonic, and energy harvesting applications

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The successful demonstration of $Ge_{1-x}Sn_x$ alloys as active material for infrared lasers paved the path to a monolithically integrated silicon photonic platform [1]. Nowadays, optically pumped group-IV lasers operating at room temperature [2] and electrically pumped lasing above 100 K [3] are achieved. The high carrier mobility is a consequence of the Sn inducing modifications in the electronic band structure and allowing the fabrication of vertical nanowires- and tunneling- field effect transistors [4]. Moreover, the recent low thermal conductivity obtained for $Ge_{1-x}Sn_x$ alloys [5] offers a real pathway toward the integration of photonics, electronics, and energy harvesting in a single fully compatible device.

The base of all these advances is the breakthrough in the epitaxy of $Ge_{1-x}Sn_x$ alloys. It presents several challenges coming from the metastable nature of these compounds, i.e. low solid solubility of Sn in Ge (<1%), very low thermal stability, and large lattice mismatch to Ge. To overcome them, growth far from thermodynamic equilibrium conditions is necessary, i.e. low deposition temperatures and high growth rates. Reduced-pressure chemical vapor deposition (RP-CVD) is one of the techniques that enable the growth of high crystalline quality of $Ge_{1-x}Sn_x$ alloys. However, achieving a precise control of the Sn content without having Sn segregation and keeping the crystalline quality high is an even greater challenge.

This work discusses the growth mechanism that offers high Sn contents, of up to 15 at.% using two different Ge gas precursors -GeH_4 and Ge_2H_6- combinated with $SnCl_4$ as Sn source. Moreover, we present an isothermal growth mode that allows the growth of $Ge_{1-x}Sn_x$/ $Ge_{1-y}Sn_y$ quantum well heterostructures with Sn content variations from 6 at.% up to 15 at.% using an industry-compatible RPCVD reactor. The effects on the Sn content and on the growth rate, as a critical process parameter, are discussed. We emphasize the role of the N_2 carrier gas, showing that tuning its flow, while keeping the process temperature, deposition pressure, and precursor fluxes constant allows us to largely vary the Sn incorporation in the Ge lattice. The proposed methodology can be extended to other reactors and can be used in the design of heterostructures for specific optoelectronic applications.

References

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