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Synthesis and stabilization of ultra-narrow direct bandgap nanoparticles of α-Sn on Si through a CMOS compatible process

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Extended Abstract

In recent years, the α-phase of tin (α-Sn) has attracted significant interest due to its extraordinary electronic properties [1,2]. Indeed, this phase features a bulk zero-bandgap topological semimetal nature [3], but its electronic structure can be modulated through applied strain. Tensile strain induces band overlap between the valence and conduction bands, conferring Dirac semimetal behaviour, while compressive strain results in bandgap opening, thereby inducing semiconductor-like behaviour with direct and narrow bandgap corresponding to the medium/far infrared range (MIR/FIR) [4,5]. Unfortunately, α-Sn is stable only below 13.5°C, which impedes most practical applications.

Objective of this work is to stabilize the α-phase of Sn on silicon, for possible integration into electronic devices and consequent possible advancements in THz technology.

A new synthesis process was designed to the aim, which is highly reproducible and CMOS-compatible, based on the baking of thin Sn films deposited on silicon, followed by microwave (MW) irradiation [6]. As it is evident from TEM and SEM inspections, the process gives rise to the formation of nanoparticles with core-shell structure and enables precise control over size and relative distance. As an example, an average nanoparticle diameter in the 10-20 nm can be obtained starting from 5 nm thick Sn films, properly tuning the process knobs. At the moment, the material is stable at room temperature (after months and years from the fabrication) [7].

As a main result, X-ray diffraction measurements performed on several samples (realized starting from different silicon substrates and different quality and thickness of Sn films); demonstrated the presence of the α-Sn in the cores of all the samples. Systematic FTIR spectroscopy outlined the presence of absorption profiles in the MIR/FIR range apart from those which were not irradiated by microwaves. Tauc modelling revealed a direct transition with energy gap values ranging between 64 and 137 meV (corresponding to 15 and 35 THz, respectively), related to the nanoparticle size.

The semiconducting properties of the MW irradiated nanoparticles suggest that, probably, during the extremely steep microwave waveform, the structures include and freeze mechanical strain inside the cores, due to the nanometric size, the shell compression and to possible silicon atoms doping favoured by the temperature ramps.

In conclusion, the obtained nanoparticles exhibit promising behaviour for future technological developments in a wide horizon of optoelectronic applications. In principle, proper engineering of the synthesis could enable tuning of morphological, optical and electrical properties favouring the realization of accordable emitters and detectors in the THz

range. Additionally, the CMOS-compatible growth process on silicon substrates opens new possibilities for integration into electronic devices, paving the way for advancements in THz technology.

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