Departamento de Física de Materiales

SEMINARIO

Spontaneous formation of Bi-rich nanostructures in $GaAs_{1-x}Bi_x$ /GaAs epilayers grown by molecular beam epitaxy: the role of thermodynamics

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Novel III-V-Bi compounds have recently emerged as a new research field in semiconductor science and technology due to their peculiar electronic properties. There are nevertheless many material-related challenges coming from the fact that III-V-Bi compounds are highly-mismatched alloys formed by the isoelectronic substitution of elements with very different size and/or electronegativity. Hence fundamental properties such as metastability, segregation, solubility limits, etc. are still under intense investigation. Recently, clustering, phase separation and atomic ordering have been reported in Ga(As,Bi), which can significantly affect optical and electrical properties. In this work we report how these features may not necessarily be detrimental, since the highly uniform Bi-rich nanostructures which spontaneously formed may constitute new functional units for future optoelectronic and/or spintronic devices, expanding the potential application of dilute bismides alloys.

The talk is divided in two parts. In the first part we investigate the microstructure of $GaAs_{1-x}Bi_x$/GaAs quantum wells (QWs) with 5% Bi by transmission electron microscopy (TEM). The QWs are grown by molecular beam epitaxy (MBE) on GaAs(001) substrates at low temperatures $T_s < 300$ °C. We find that regardless of their different T_s all investigated QWs exhibit: (i) clear and well-defined lateral composition modulations (LCM); (ii) indication of vertical stacking of the composition modulation, and (iii) Bi surface segregation with a segregation efficiency $R > 0.9$. Indeed, the microstructure resembles an array of perfectly aligned (both laterally and vertically) nanopillars-like structures. On one side, the formation of Bi-rich nanopillars is explained from thermodynamics: the large miscibility gap between GaAs and Bi can lead to a particularly strong tendency to phase separation. On the other hand, the high degree in vertical alignment of the nanopillars (between different QWs) can be understood in terms of the strain fields associated to the Bi-rich areas.

In the second part, we report on the TEM investigation of the microstructure of Ga(As,Bi) epilayers after rapid thermal annealing. Bi-containing clusters are identified in various samples depending on the growth conditions. The clusters exhibit a relatively homogeneous size distribution. Depending on the annealing temperature and duration, the Bi-containing clusters show different sizes ranging from 10 to 20 nm, as well as different crystallographic phases, being either coherently strained zincblende $GaAs_{1-x}Bi_x$ [zb Bi-rich Ga(As, Bi)] clusters or rhombohedral pure Bi (rh-Bi) clusters. We found that: (1) the formation of the zb Bi-rich Ga(As, Bi) clusters is driven by the intrinsic tendency of the alloy to phase separate and is mediated by the native point defects present in the low temperature grown epilayers; (2) there is a phase transformation from zb Bi-rich Ga (As, Bi) to rh-Bi clusters. The nanosized rh-Bi crystals nucleate in the zincblende {111} planes and grow until depletion of the Bi atoms in the GaAs matrix. Furthermore, our study reveals the possibility to realize self-organized zb Bi-rich Ga(As, Bi) clusters that may exhibit quantum dot (QD)-like features.