Strain fluctuations in a real [001]-oriented zinc-blende-structure surface quantum well

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Tóm tắt

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Nội dung

In the last years, the two-dimensional electron gas (2DEG) has been formed at a surface of several semiconduc-tor heterostructures.[1 - 5] The free surface in a surface quantum well (SQW) exhibits a distinction from buried interfaces in a quantum well (QW). Accessibility of one face of a SQW enables gradual etching of the well width to study the width dependence of its observable properties. Moreover, the free surface of a SQW imposes a boundary condition for elastic lattice deformation in the well, which is strikingly different from that by a buried interface in a QW.

On the other hand, elastic lattice deformation due to lat-tice mismatch between various layers of a semiconductor heterostructure is known[6] to result in both microscopic ef-fects, e.g., change of the band gap and lifting of the degen-eracy of the valence band, and in macroscopic ones, e.g., piezoelectric field. Therefore, a wide variety of basic proper-ties of a QW is expected to significantly change if its bound-aries are modified, in particular, if a SQW is formed, for instance, by removing the top barrier layer of the QW by selective chemical etching.[4]

Up to now, SQW's have been studied much less than QW's and mainly in conjunction with passivation[2,3] and op-tical phenomena.[4] A thorough study of diverse physical properties of SQW's is, therefore, of some interest. The under-standing of them is also of benefit for the modeling of lateral quantization effects in etched quantum wires and quantum dots,[2 - 4,7] where the lateral barriers are defined by open surfaces.[8,9]

Recently, it has been pointed out[10 - 12] that interface rough-ness in a semiconductor heterostructure causes random fluctuations in the strain field. Feenstra and Lutz[11] proved that for Si/SiGe systems strain variations generate random deformation potentials as a new scattering mechanism, which yields much better agreement with experimental data than the well-known scatterings do. Further, Quang and co-workers[12] found that for a QW made of zinc-blende material strain variations generate a random piezoelectric field. This field is a new scattering mechanism and offers an accurate way to explain the mobility of strained InGaAs-based QW's, which cannot be understood by the well-known scattering sources.

Thus, the aim of this paper is to extend our earlier theory of effects due to strain fluctuations in QW's (Ref. 12) to the case of SQW's that are made of zinc-blende material, espe-cially grown on a (001) substrate. Thereby, we explore which of the above-mentioned disorder interactions exists in a SQW and compare their impacts from a free rough surface in a SQW and from a buried one in a QW.

To start with, we recall the main arguments for ideal SQW's, which are composed of a strained zinc-blende layer grown pseudomorphically on a substrate, where the well thickness is much smaller than the critical one but the sub-strate thickness is larger. It is known[6] that if the substrate has been oriented along a high symmetry direction, e.g., [001] and the open surface is assumed to be ideal, i.e., absolutely flat, the stress field inside of the well is uniform and biaxial. Accordingly, the strain field is uniform and has no shear components, i.e., with zero off-diagonal ones. Consequently, ideal SQW's present neither a piezoelectric polarization nor any piezoelectric field.

However, as mentioned above, interface roughness can cause drastic modification in the strain field. This turns out to depend very sensitively on the condition of the interface to be open or buried. Indeed, in a QW with buried interfaces a fraction of the elastic strain energy in the well is transmitted during growth to unstrained barriers, so lowering the total energy of the well, whereas in a SQW with an open surface (vacuum or air/well) the surface evolution is dictated by a boundary condition that the surface is traction free.[13]

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