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Invited

The Evolution of Semiconductor Quantum Structures
Do-It-Yourself Quantum Mechanics

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Following the past two decade evolutionary path in the interdisciplinary research of semiconductor quantum structures, significant milestones associated with technological advances, are presented with emphasis on electric field-induced effects in the realm of the nanoscale, low-dimensional physics.

Research on semiconductor superlattices was initiated with a proposal by Esaki and Tsu[1] for a periodic structure "engineered" with epitaxy of alternating ultra-thin layers. This was, perhaps, the first proposal of "designed semiconductor quantum structure".

Quantum mechanics, started in the early 20th century, has been playing an indispensable role in our understanding of the properties of semiconductors. In the proposal, however, we asserted that semiconductor structures which would exhibit unprecedented transport and optical properties, could be designed using the principles of quantum theory and synthesized with the advanced techniques of thin-film growth.

The electron dynamics with applied voltages in the superlattice direction was analyzed first in terms of the band model,[1] and later from the tunneling point of view.[2] Both analyses led to the prediction of intriguing electron transport, including a differential negative resistance which arises from resonant tunneling or Bragg reflection at the minizone boundary.

In 1972, Esaki et al.[3] found that an MBE-grown GaAs-GaAlAs superlattice exhibited a weak negative resistance in its transport properties, which was, for the first time, interpreted in terms of the above-mentioned superlattice effect. In 1974, Esaki and Chang[4] reported the oscillatory transport behavior for a tight-binding superlattice and Chang, Esaki and Tsu[5] observed resonant tunneling in double-barriers. In the same year, the optical absorption measurements of Dingle et al.[6] showed the quantization of confined electrons in quantum wells. It is interesting to see that the well-known elementary examples described in quantum mechanics textbooks were manifested themselves in these pioneering experiments.

With increased availability of advanced thin-film growth and microfabrication facilities, studies of the nanoscale, low-dimensional science have since then proliferated at an explosive rate:[7] A variety of families of structures and devices have emerged, exhibiting extraordinary transport and optical properties: some of them, such as ultrahigh electron mobilities, large Stark shifts or the observation of Stark ladders, may not be possible in any "natural" crystal. Thus, this new degree of freedom offered in semiconductor research "through advanced material engineering" has inspired many ingenious experiments, resulting in observations of not only predicted effects but also totally unknown phenomena. It is estimated that currently half of semiconductor research in the world is devoted to this subject.

Activities in this new frontier of semiconductor physics, in turn, give immeasurable stimulus to device physics, leading to unprecedented transport and optoelectronic devices.

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