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This report summarizes the most important result obtained during the short span of this grant, namely, the (theoretical) possibility of electric-field induced TE to TM mode switching in semiconductor quantum well lasers under moderate tensile strain.

14. SUBJECT TERMS
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FINAL REPORT

Emilio E. Mendez

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STATEMENT OF WORK

In the last twenty years, semiconductor quantum structures prepared epitaxially have exhibited unprecedented transport, optical and magnetic properties, which have stimulated device inventions for information and communication systems. Investigation in quantum wells and superlattices has resulted in a fertile field that now constitutes about one third of world-wide semiconductor research, and whose impact goes beyond semiconductors to reach systems involving metals and insulators.

The focus of this work has been on novel optical properties of quantum wells and superlattices subjected to an electric field perpendicular to the interface planes. The work was originally planned for three years (from July 1994 to June 1997) and to be carried out by four scientists. Because of the departure of the principal investigator from IBM to become a Professor of Physics at the State University of New York at Stony Brook in early 1995, the work was interrupted at the end of 1994 and the ARO grant to IBM was terminated.

Given the short duration of the project, it has only been possible to address one of the three topics discussed in the original proposal, and only to a very preliminary level. In what follows, we summarize the accomplishments for the period July -December, 1994 on the possibility of controlling with an electric field the electromagnetic modes of light emission in quantum wellls.

MOST IMPORTANT RESULTS

The application of an electric field along the direction of a semiconductor quantum well results in a shift to lower energy of the ground quantum state. This effect, which is frequently known as the quantum-confined Stark effect (or simply the Stark effect), is approximately proportional to the effective mass of the confined particle. Therefore, for a quantum well formed in the valence band of a typical heterostructure system, say GaAs-GaAlAs, the Stark shift is larger for the ground heavy-hole state than for the corresponding light-hole state.

There are instances, however, in which the light-hole state can be the lowest-energy level in the valence band. This is the case with a quantum well under an in-plane tensile stress, produced, for example, by a lattice mismatch between the well and barrier materials. If an electric field were then applied to the well, the larger shift of the heavy-hole state would bring it closer to the light hole and, for strong enough fields, the initial ordering could be reversed, with the heavy-hole level as the absolute ground state of the valence band.

This prediction is significant because a semiconductor laser whose active region consists of a quantum well with the above characteristics would produce stimulated emission with TM polarization. If a strong electric field were subsequently applied to the well, its polarization would switch to a TE mode. We would then have a field-controlled, polarization-switchable laser, which has obvious interest for optical communications.

We have done initial calculations to assess the feasibility of this effect for practical applications. Specifically, we have calculated the effect of an external electric field on the gain of a laser diode whose active region consists of a quantum well under a moderate biaxial tensile strain. We have focussed our attention on a 150Å well under a tensile strain ε=0.12%. Such a situation would occur in a $In_{0.53}Ga_{0.47}As$ layer clad between relaxed $In_{0.54}Al_{0.46}As$ regions.

At zero electric field the heavy-hole level is still the ground state for the valence-band well and the peak gain of the TE electromagnetic mode is slightly larger than that of the TM mode. As the electric field increases, the peak gains of both TE and TM modes shift to lower energy (as a consequence of the Stark shift) and their values decrease (as a result of the reduced overlap between electron and hole wavefunctions). Moreover, since this decrease is slower for the TM mode, the TM gain already exceeds the TE gain at 50kV/cm.

Physically, this result follows from the proportionality of the gain to the dipole moment, summed over the whole Brillouin zone, for the optical transitions between the lowest conduction state and the valence subbands. The calculated cross-over suggests that indeed mode switching is possible even in the presence of very modest strains, from TE to TM. More complete calculations should consider the situation of a larger strain combined with moderate electric fields, in which case TM to TE switching might be possible. Undoubtedly, systematic experimental work would be needed to confirm those predictions.

PUBLICATIONS

- *Feasibility of TE-TM Mode Changeable Tensile -Strained Quantum Well Lasers*, M. Ogawa and E. E. Mendez, Proceedings of the 14th International Conference on the Physics of Semiconductors, Vancouver, Canada, August, 1994 (in press).

SCIENTIFIC PERSONNEL SUPPORTED BY THE PROJECT

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