

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		DTIC SELECTED		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		SCHEDULE 1 0 1995		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		F		5. MONITORING ORGANIZATION REPORT NUMBER(S) ARO 26015.6-PH	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)				5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Princeton University		6b. OFFICE SYMBOL (if applicable)		7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office	
6c. ADDRESS (City, State, and ZIP Code) Department of Electrical Engineering Princeton, NJ 08544				7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office		8b. OFFICE SYMBOL (if applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAL03-89-K-0036	
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) ELECTRON TRANSPORT IN HETEROJUNCTION SUPERLATTICES					
12. PERSONAL AUTHOR(S) D.C. Tsui and M. Shayegan					
13a. TYPE OF REPORT FINAL		13b. TIME COVERED FROM 4/15/89 TO 8/31/92		14. DATE OF REPORT (Year, Month, Day) May 9, 1995	15. PAGE COUNT
16. SUPPLEMENTARY NOTATION The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP			
19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>This is a final report on the research carried out under the ARO contract DAAL03-89-K-0036 (ARO proposal number 26015-PH) from April 15, 1989 to August 31, 1992. It describes briefly three accomplishments in the area of resonant tunneling through double-barrier devices made of GaAs/AlGaAs heterostructures. They include results on: (1) magnetotunneling characteristics, (2) noise characteristics, and (3) resonant tunneling from a two-dimensional electron system into one-dimensional subbands of a quantum wire, realized through a novel growth geometry.</p>					
DTIC QUALITY INSPECTED 5					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL	

# ELECTRON TRANSPORT IN HETEROJUNCTION SUPERLATTICES

## FINAL REPORT

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May 9, 1995

U.S. ARMY RESEARCH OFFICE

Contract DAAL03-89-K-0036  
(ARO Proposal No. 26015-PH)

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## Electron transport in heterojunction superlattices

Following our work performed under a previous ARO contract, which included the first experimental demonstration of the importance of many-electron effect in transport through double-barrier resonant tunneling structures and observation of an intrinsic electrical bistability, we concentrated on several new aspects of tunneling through such structures:

### 1. Magnetotunneling characteristics

We made measurements of the current-voltage characteristics of an asymmetric GaAs/Al<sub>x</sub>As double-barrier resonant-tunneling device in a magnetic field  $\mathbf{B}$  parallel to the tunneling direction. In the resonant-tunneling regime the magnetic field induces weak steplike features in the  $I(V)$  curve and sawtooth oscillations in the  $I(B)$  curve that are periodic in inverse field. We explain these magnetotunneling features by Landau quantization of the three-dimensional states in the emitter and the two-dimensional states in the well, which induces steplike structure in the tunneling supply function. The experimental  $I(V,B)$  line shape is in good agreement with self-consistent numerical calculations.

We also made measurements on the magnetotunneling characteristics of a high-quality bistable double-barrier resonant tunneling device in magnetic fields transverse to the tunneling direction. The transverse magnetic field  $B_{\perp}$  causes complex, non-monotonic shifts in the position of the resonant current peak in the  $I(V)$  curve. The resonant peak is also strongly broadened by  $B_{\perp}$ , and the peak current is suppressed. The intrinsic bistability of the device is quenched for  $B_{\perp} > 5$  T. We explain these

effects by invoking the magnetic-field-induced change in transverse momentum  $\Delta k$  as electrons tunnel into the well. The change  $\Delta k$  alters both the tunneling supply function and the tunneling probability for a given alignment of the resonant subband and the emitter electrode. Self-consistent calculations based on this model reproduce the complex behavior of resonant peak position and explain the experimentally observed magnetic-field effects.

## **2. Noise characteristics**

The noise characteristics of the double-barrier resonant-tunneling structures depend on the degree of phase coherence of the tunneling of electrons through the two barriers. We made measurements of the noise characteristics of double-barrier resonant-tunneling structures and systematically studied the behavior of noise on three samples with different barrier structures. Our results provide direct evidence of incoherent tunneling and can be qualitatively understood if phase incoherence of the tunneling processes is taken into account.

## **3. Resonant tunneling of two-dimensional electrons into one-dimensional subbands of a quantum wire**

In the standard experimental system commonly employed in research on double-barrier resonant-tunneling structures the tunneling occurs from a three-dimensional density of states in the emitter into two-dimensional subbands confined by the double-barrier potential.

To study tunneling phenomenon in a novel geometry, we employed liquid-phase epitaxy regrowth on the edge of *in situ* cleaved substrates to create a vertical two-

dimensional electron gas in a double-barrier tunneling potential. Resonant tunneling of two-dimensional electrons through one-dimensional quantum wire subbands was unambiguously identified by negative differential resistance features in the transport characteristics. The bias positions of these features agree with simple tunneling theory estimates based on conservation laws and the calculated band alignment in the structure under bias.

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