The formation, expansion, and readjustment of electric field domains in multiquantum well stacks is described and explained in terms of sequential resonant tunneling. These effects are used to control the multiband spectral response in IR detector applications of these structures.

The formation of electric field domains (EFD) was first observed in bulk GaAs and is mostly known as the cause of Gunn oscillations. It is explained in terms of the negative differential resistance (NDR) which occurs because of the electron transfer from the \( \Gamma \) to the \( X \) or \( L \) valleys. Esaki and Chang first observed the formation of static EFDs in multiquantum wells (MQW); this phenomenon was attributed to the NDR which arises due to sequential resonant tunneling (SRT) between subbands in adjacent wells.

Recently, we demonstrated the operation of a tunable quantum well infrared detector which was based on the formation of EFDs in a MQW device. In this letter, we report on an investigation designed to determine the parameters which govern EFD formation and expansion. We show theoretically and experimentally how the proper choice of well widths, heights, and doping determines the electric field domain profile.

First, we discuss EFDs in the three-stack MQW device presented in Ref. 7. In this device the superlattice clad by two \( n \)-doped contact layers, consisted of three stacks of 25 QW each; the first 25 wells were 3.9 nm wide and were separated by \( \text{Al}_x\text{Ga}_{1-x}\text{As} \) \( (x=0.38) \) barriers; the second stack consisted of 4.4 nm wide wells with \( (x=0.3) \) barriers; the last stack had 5.0 nm wide wells and \( (x=0.24) \) barriers. All the barriers were 44 nm wide; the wells and the contacts were uniformly doped with Si to \( n=4\times10^{18} \) cm\(^{-3}\).

The absorption spectrum at room temperature shows three peaks at 1364, 1080, and 920 cm\(^{-1}\) obeying intersubband selection rules for the polarization of the incident light. Figure 1 displays the smoothed photocurrent spectral response of a mesa structure, 200 \( \mu \)m in diameter at 7 K, for different values of the applied voltage. The polarity is defined in Fig. 2. We see that at different ranges of applied bias, only some of the peaks in the photocurrent are present. This was explained by the formation of high and low electric field domains in the device. The light is absorbed in all three stacks of QWs but only photoexcited carriers which are in a region with high electric field can be swept out of the QW and contribute to the current. Those in the low field region have a high probability of being recaptured by their own well, contributing only negligibly to the current.

A second indication of the presence of EFDs in the device comes from dark current measurements. A fine structure in the plateaus of the \( I-V \) curve, corresponds to regions of NDR. This is due to SRT, which occurs whenever the ground level of a well is aligned with the excited level of the adjacent well. Under an arbitrary applied bias, a uniform distribution of electric field is not stable because all of the QWs will be out of resonance, i.e., none of the energy levels of pairs of adjacent wells will be aligned. Instead, the system will settle into a different configuration in which the electric field profile includes high and low field regions. In the high field region we have ground level to excited level SRT, and in the low electric field region ground level to ground level SRT. Transport within each domain is resonant, while at the boundary between the two regions it is generally nonresonant. This boundary then acts as a bottleneck that limits the current. There should
**Control of electric field domain formation in multiquantum well structures**

1. **REPORT DATE**  
   JUN 1993

2. **REPORT TYPE**

3. **DATES COVERED**
   00-00-1993 to 00-00-1993

4. **TITLE AND SUBTITLE**

5. **AUTHOR(S)**

6. **PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
   California Institute of Technology, Department of Applied Physics, Pasadena, CA, 91125

7. **SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

8. **PERFORMING ORGANIZATION REPORT NUMBER**

9. **SPONSOR/MONITOR'S ACRONYM(S)**

10. **SPONSOR/MONITOR’S REPORT NUMBER(S)**

11. **DISTRIBUTION/AVAILABILITY STATEMENT**
   Approved for public release; distribution unlimited

12. **SUPPLEMENTARY NOTES**

13. **ABSTRACT**

14. **SUBJECT TERMS**

15. **SECURITY CLASSIFICATION OF:**

   - a. REPORT: unclassified
   - b. ABSTRACT: unclassified
   - c. THIS PAGE: unclassified

16. **LIMITATION OF ABSTRACT**

17. **NUMBER OF PAGES**
   3

18. **NAME OF RESPONSIBLE PERSON**

---

Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
also be some charge accumulation or depletion at this boundary because of the change in the slope of electric fields, as required by Poisson’s equation. This also has to be considered when determining the current flow through the structure. An increase in the bias will cause more QWs to enter the high field domain (HFD) region, and this is reflected by the oscillatory behavior in the $I$-$V$ curve.

In the case of our sample, several electric field distributions across the three stacks of QWs are possible [Fig. 2(a)]. Some of these have only high field domain (HFD) in one of the stacks and others have a combination of HFDs and LFDs (low field domains) in all the stacks. The main rule used to determine different field profiles across the structure is that we may use only the electric field values which result in alignment of energy levels between adjacent wells. In addition, the total voltage drop must equal the applied voltage. This results in a large number of possible configurations. The actual electric field distribution should satisfy self-consistently Poisson’s equation and the equation of current continuity along the superlattice. Because of the complexity of the transport calculations in MQWs a detailed study, which should also include a stability analysis, is very complicated. In this letter, instead, we try to extract some of the parameters which are important for HFD formation, and use them to design samples with a desired electric field distribution.

One of the important parameters is the amount of charge accumulation or depletion at the boundaries, where the slope of the electric field changes. This charge, by altering the tunneling process (resonant or nonresonant) at that boundary, can limit the total current which flows through the structure. If the transport at the bound-
Bias voltages, with an added short wavelength peak corre- 

ting to our formalism we set out to design a two-stack MQW 

current, i.e., a detector with a long wavelength peak at low 

detector which displays the opposite pattern in the photo-

cept. Figure 3 displays the photocurrent of a second two-

stack MQW detector where the barriers in the stack (b) 
(having absorption peak at longer wavelength) were shorten-

to 20 nm. [Stack (a): 4.0 nm GaAs wells separated by 
44 nm Al_{0.35}Ga_{0.65}As barriers. Stack (b): 4.7 nm GaAs 
well separated by 20 nm Al_{0.30}Ga_{0.70}As barriers.] By this 
mean we can achieve the requirement that the electric field 
for ground state to excited state SRT be increased in stack 
(b) and become larger than the corresponding value of the 
electric field in stack (a). As a result we see that this time 
the peak at the longer wavelength appears first, and then, 
by increasing the bias further, the peak at the shorter wave-

length appears. It is interesting to note that the spectral 
photoresponse of these two-stack MQW devices has a simi-

lar behavior when we reverse the polarity of the applied 

bias (not shown in the figure); this is in contrast with the 
switching behavior observed in the three-stack MQW de-

vice. This shows the importance of the LFD in the third 
stack as a current limiting process. A more detailed anal-

ysis of the transport in these devices, considering bound to 
continuum SRT, is beyond the scope of this letter and will 
be presented separately.

In conclusion, we have discussed some of the impor-
tant parameters governing the formation, expansion, and 
readjustment of electric field domains in multiquantum 

well structures. For the first time, we showed how the 

continuum pattern of electric field domain formation can be 
manipulated by careful design of the device.

This work was supported by DARPA and the Office of 

Naval Research.


Kazarinov and R. A. Suris, Sov. Phys. Semicond. 6, 120 (1972); ibid, 5, 
707 (1971).
(1986).
4. K. K. Choi, B. F. Levine, R. J. Malik, J. Walker, and C. G. Beeha, 
Phys. Lett. 60, 7397 (1992); A. Sibile, J. F. Palmier, and F. Mollot, 
ibid, 60 457 (1992); A. Sibile, J. F. Palmier, C. Minot, and F. Mollot, 
7. I. Gravé, A. Shakouri, N. Kuze, and A. Yariv, Appl. Phys. Lett. 60, 