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Possibilities for LWIR Detectors using MBE-grown Si(/$Si_{1-x}Ge_x$) Structures

R. J. Hauenstein, R. H. Miles, and M. H. Young

Hughes Research Laboratories

Malibu, California 90265

Traditionally, LWIR detection in Si-based structures has involved either extrinsic Si or Si/metal Schottky barrier devices. Molecular beam epitaxially (MBE) grown Si and Si/$Si_{1-x}Ge_x$ heterostructures offer new possibilities for LWIR detection, including sensors based on intersubband transitions as well as improved conventional devices. The improvement in doping profile control of MBE in comparison with conventional chemical vapor deposited (CVD) Si films has resulted in the successful growth of extrinsic Si:Ga, blocked impurity-band conduction detectors. These structures exhibit a highly abrupt step change in dopant profile between detecting and blocking layers which is extremely difficult or impossible to achieve through conventional epitaxial growth techniques. Through alloying Si with Ge, Schottky barrier infrared detectors are possible, with barrier height values between those involving pure Si or Ge semiconducting materials alone. For both n-type and p-type structures, strain effects can split the band edges, thereby splitting the Schottky threshold and altering the spectral response. Our measurements of photoresponse of n-type Au/$Si_{1-x}Ge_x$ Schottky barriers demonstrate this effect. For intersubband multiquntum well (MQW) LWIR detection, $Si_{1-x}Ge_x$/Si detectors grown on Si substrates promise comparable absorption coefficients to that of the Ga(Al)As system while in addition offering the fundamental advantage of response to normally incident light as well as the practical advantage of Si-compatibility. We have grown $Si_{1-x}Ge_x$/Si MQW structures aimed at sensitivity to IR in the 8 to 12 μm region and longer, guided by recent theoretical work.[1] Preliminary measurements of our n- and p-type $Si_{1-x}Ge_x$/Si MQW structures will be presented.

[1] Y. Rajakarunanayake and T. C. McGill, *Proc. of the 17th Annual Meeting of the Physics and Chemistry of Semiconductor Interfaces*, Clearwater, 1990.

POSSIBILITIES FOR LWIR DETECTORS USING MBE-GROWN Si(/SiGe) STRUCTURES

R.J. HAUENSTEIN
HUGHES RESEARCH LABORATORIES

OUTLINE

- INTRODUCTION
- EXTRINSIC Si DETECTORS
- $Si_{1-x}Ge_x$ /Si MQW DETECTORS
- SCHOTTKY BARRIERS ON $Si_{1-x}Ge_x$
- SUMMARY

TRADITIONAL MID TO LONG WAVELENGTH IR DETECTORS IN Si

- EXTRINSIC DETECTORS
  - PC TYPE
  - BLOCKED IBC TYPE
- SCHOTTKY DETECTORS
  - e.g., PtSi/Si

MATERIALS PRODUCED BY Si MBE

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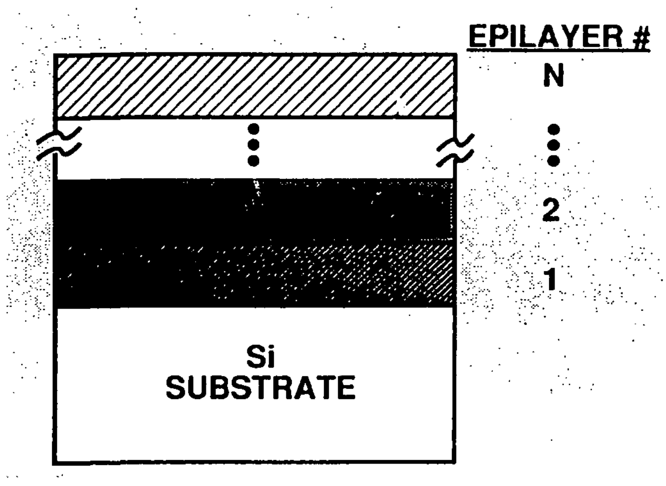


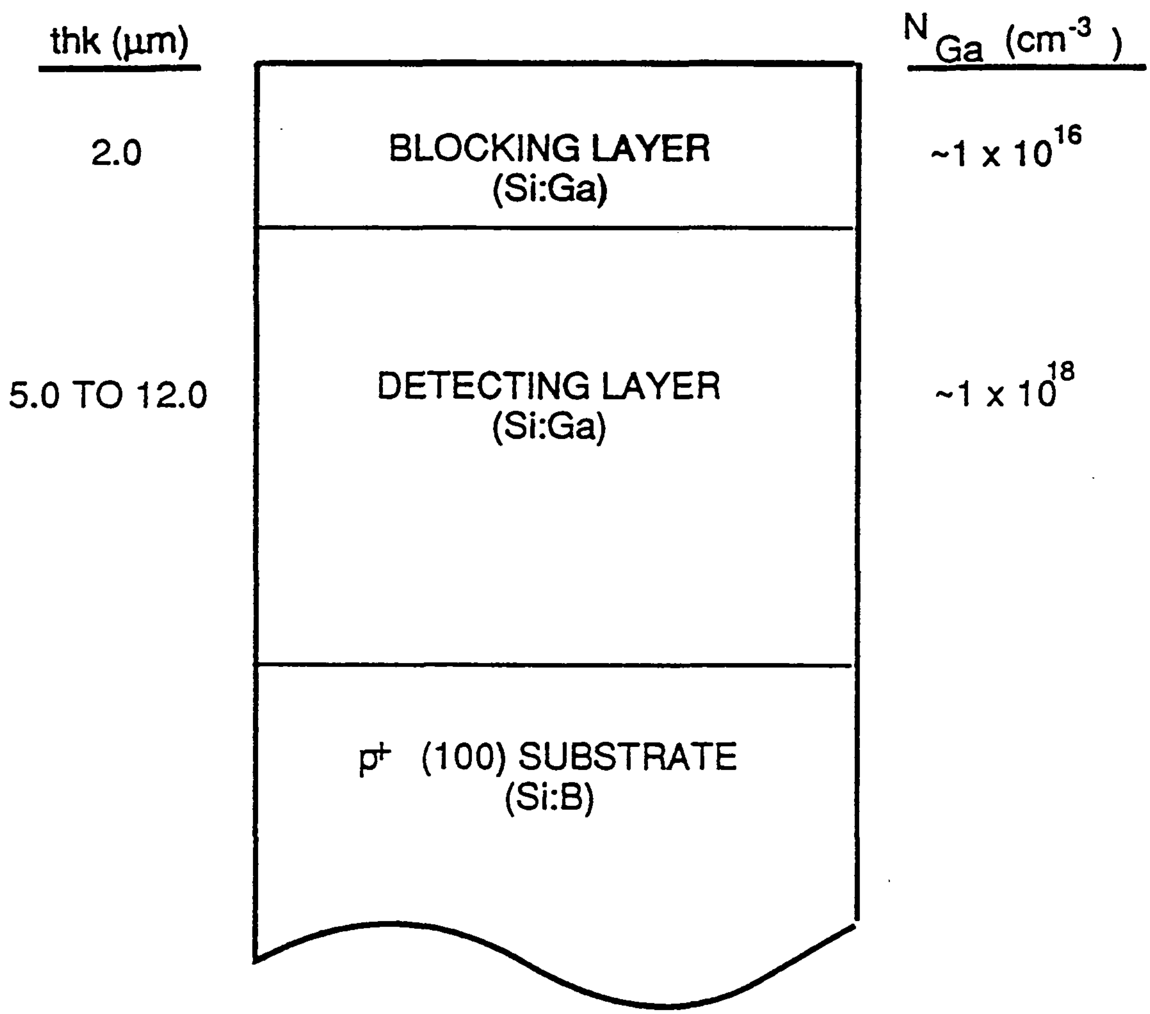
- MANY EPITAXIAL COMBINATIONS POSSIBLE
  - $Si_{1-x}Ge_x$ (COHERENTLY STRAINED)
  - SILICIDES (M_xSi_y)
  - SELECTIVELY DOPED Si
  - OTHER

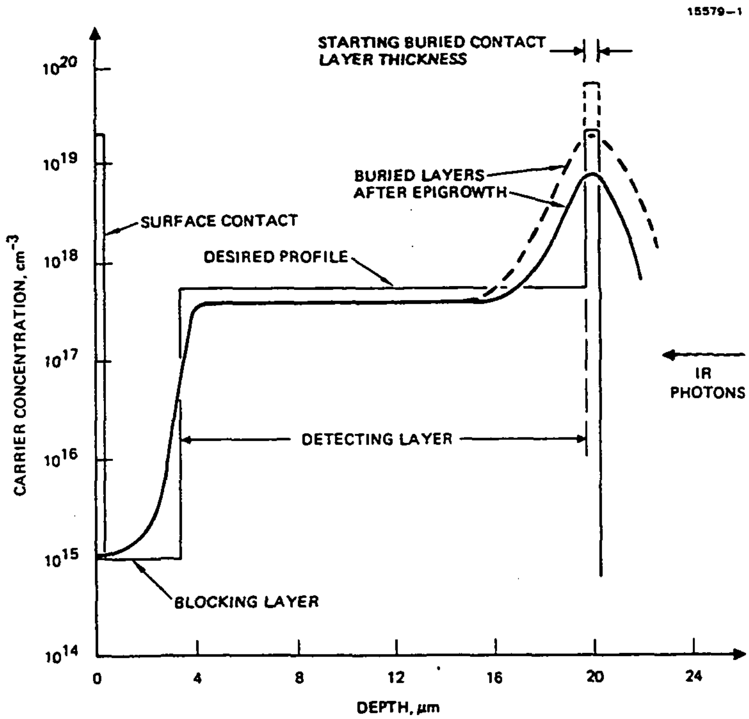
EXTRINSIC Si DETECTORS

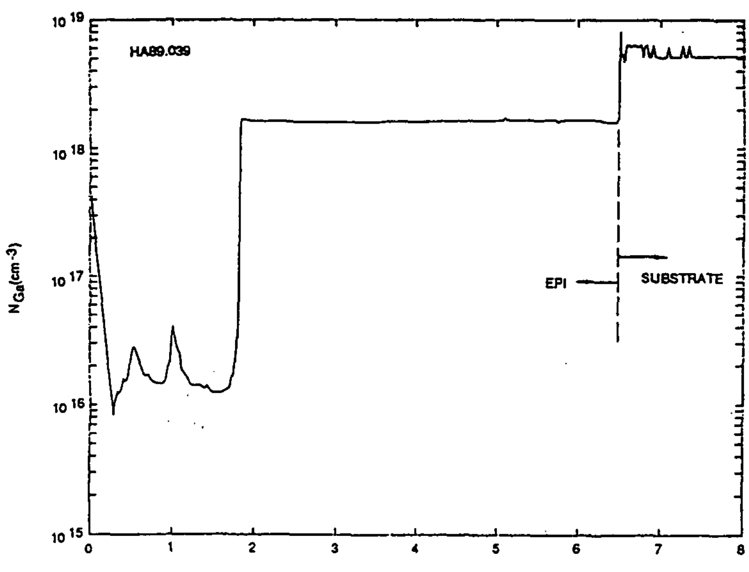
- MBE ⇒ SUPERIOR DOPANT PROFILE CONTROL FOR FAST DIFFUSERS (e.g., Ga IN Si)

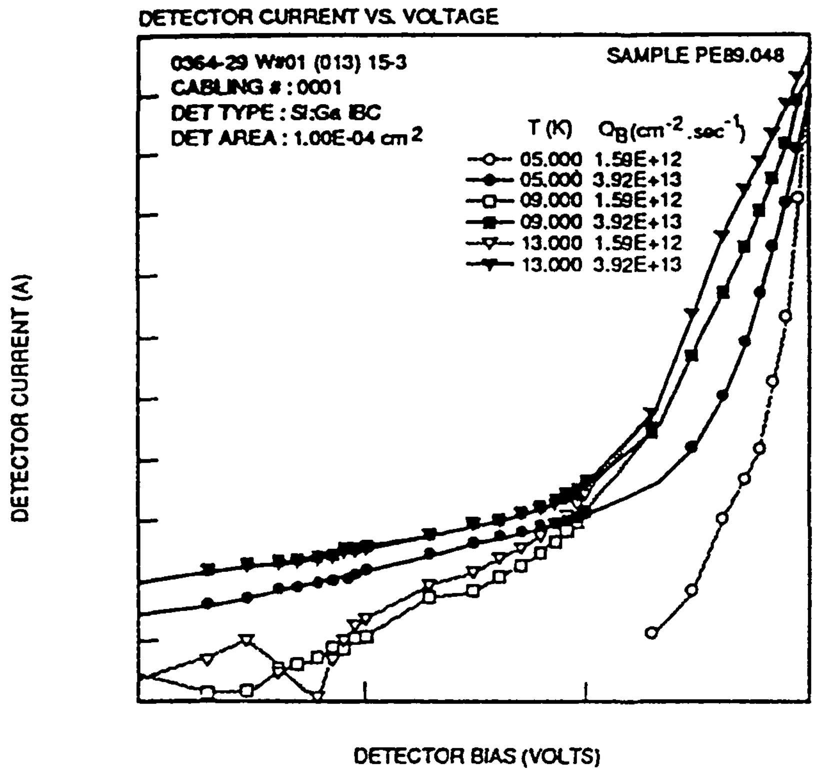
  CONCENTRATIONS > SOLID SOLUBILITY SOMETIMES POSSIBLE

- MBE + LOW-ENERGY ION IMPLANT PROVIDES GREAT FLEXIBILITY

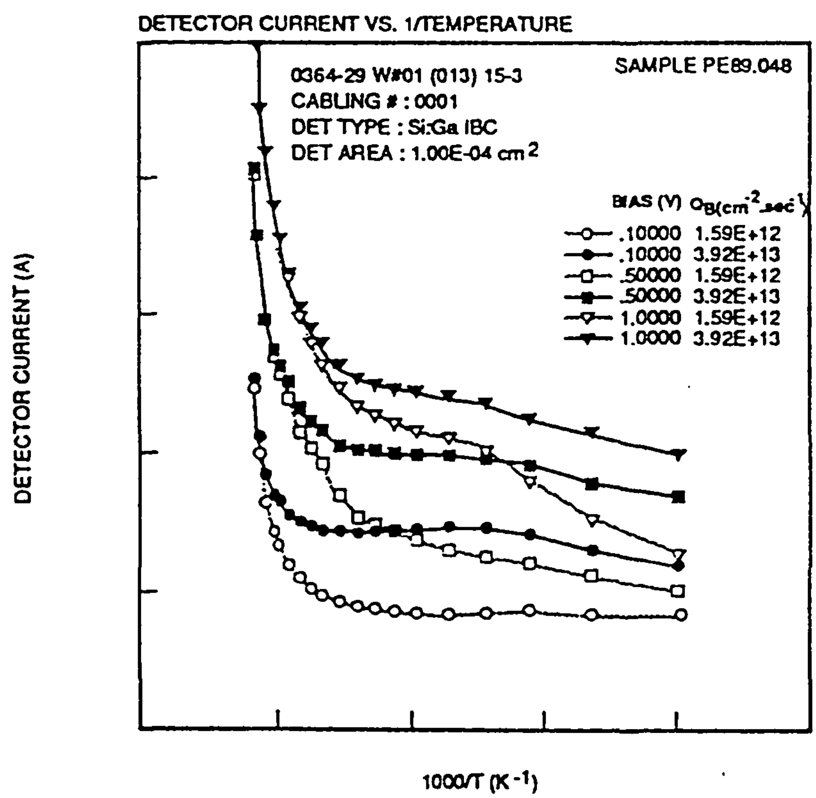



15579-1
STARTING BURIED CONTACT LAYER THICKNESS
BURIED LAYERS AFTER EPIGROWTH
SURFACE CONTACT
DESIRED PROFILE
DETECTING LAYER
IR PHOTONS
BLOCKING LAYER
CARRIER CONCENTRATION, cm-3
DEPTH, μm

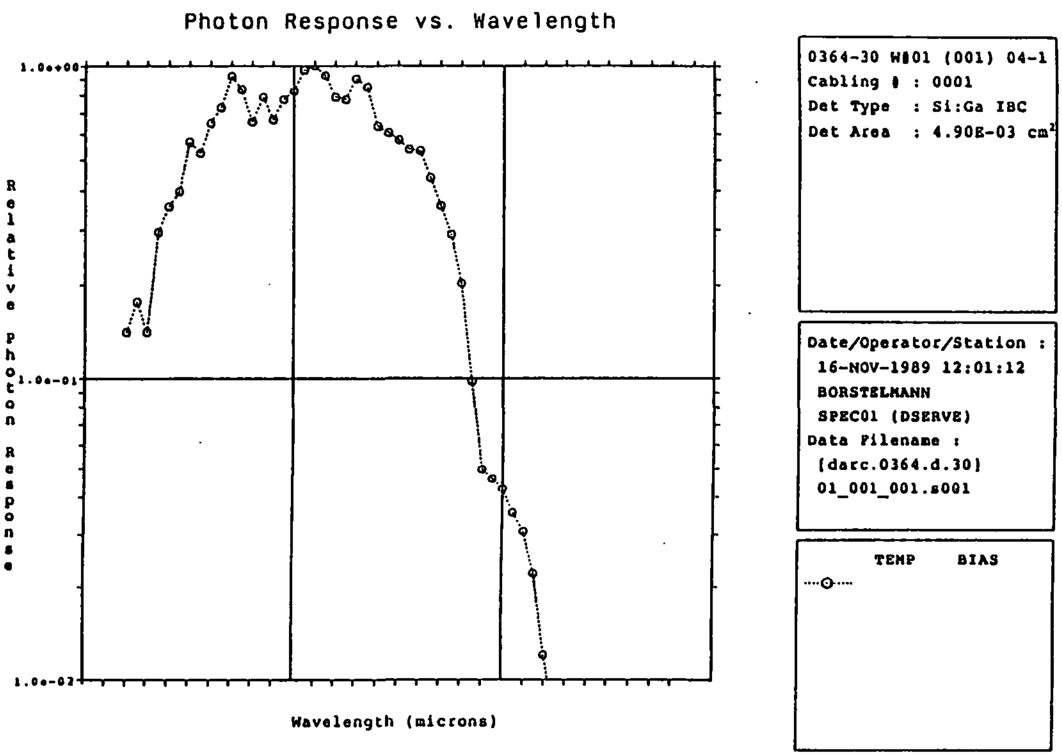

HA89.039
EPI
SUBSTRATE
NGa(cm-3)
DEPTH (μm)


DETECTOR CURRENT VS. VOLTAGE
0364-29 W#01 (013) 15-3
CABLING # : 0001
DET TYPE : Si:Ga IBC
DET AREA : 1.00E-04 cm 2
SAMPLE PE89.048
T (K) Q_B(cm^{-2}.sec^{-1})
05.000 1.59E+12
05.000 3.92E+13
09.000 1.59E+12
09.000 3.92E+13
13.000 1.59E+12
13.000 3.92E+13
DETECTOR CURRENT (A)
DETECTOR BIAS (VOLTS)

a)


DETECTOR CURRENT VS. 1/TEMPERATURE
0364-29 W#01 (013) 15-3
CABLING # : 0001
DET TYPE : Si:Ga IBC
DET AREA : 1.00E-04 cm 2
SAMPLE PE89.048
BIAS (V) Q_B(cm^{-2}.sec^{-1})
.10000 1.59E+12
.10000 3.92E+13
.50000 1.59E+12
.50000 3.92E+13
1.0000 1.59E+12
1.0000 3.92E+13
DETECTOR CURRENT (A)
1000/T (K^{-1})

b)



MBE Si:Ga BLOCKED IBC RESULTS

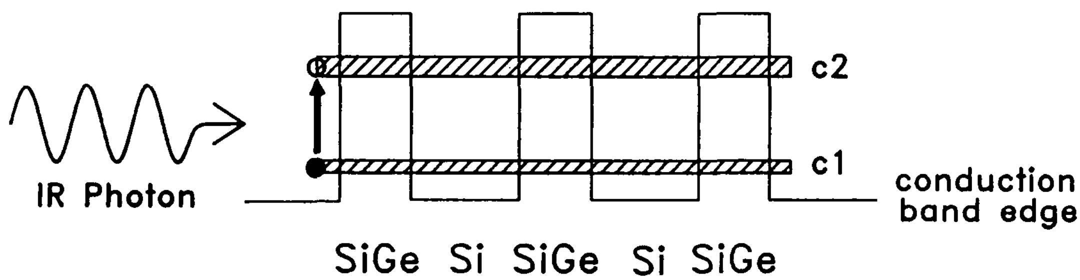
- IBC BEHAVIOR DEMONSTRATED

- WAVELENGTH RESPONSE GOOD (~ 12 μm PEAK)
  HOWEVER: POOR Q.E. DUE TO
  - LIMITED PURITY (NEED ~ 10^{12} CM $^{-3}$!)
  - TOO MANY PARTICULATES

HRL IS DEVELOPING A GAS-SOURCE Si MBE TECHNIQUE TO IMPROVE UPON ABOVE RESULTS

SiGe/Si MULTI-QUANTUM WELL DETECTOR

Intersubband Absorption



- Tunable response throughout infrared
- Normal-incidence absorption
- Predicted absorption stronger than GaAs-based

SiGe/Si MQWS – IMPORTANT ISSUES

- **STRAIN**
  - **– CRITICAL THICKNESS(ES)**
  - **– EFFECT ON BAND STRUCTURE**
- **COND. BAND ANISOTROPY**
- **GROWTH ISSUES**
  - **– GOOD "RELAXED" LAYER**
  - **– n-TYPE DOPING**
  - **– UNIFORMITY OF THIN LAYERS**

$Si_{1-x}Ge_x$ ON Si

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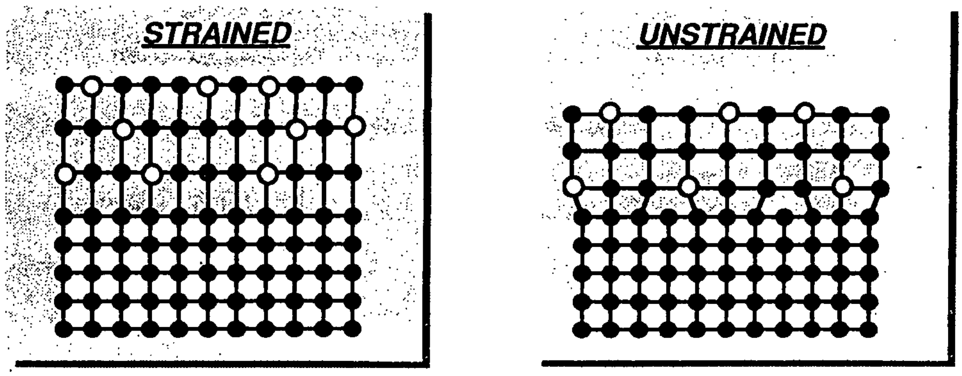
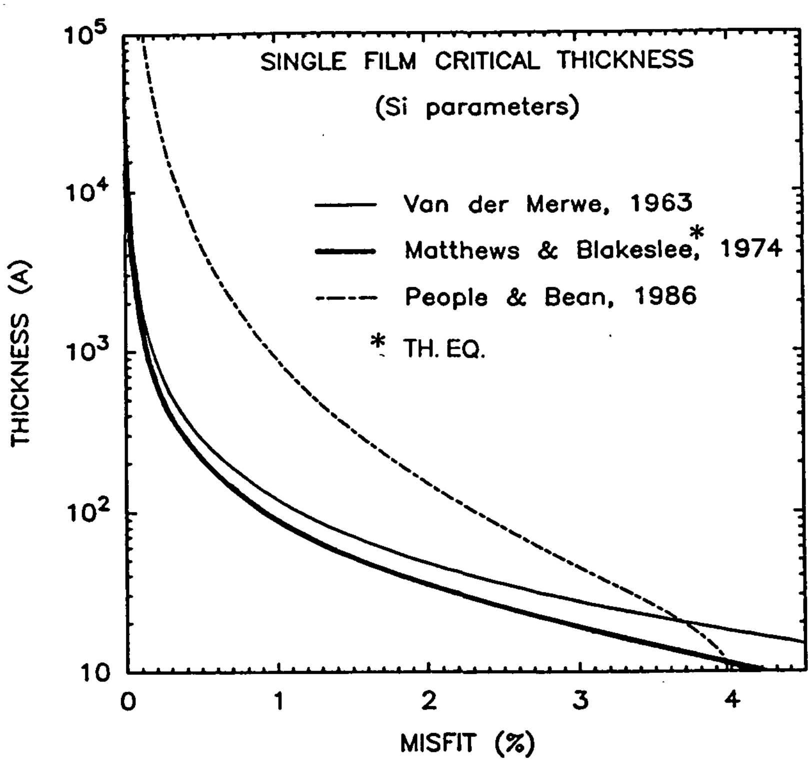
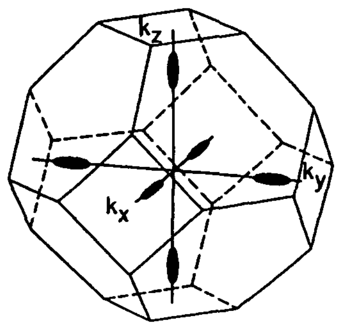
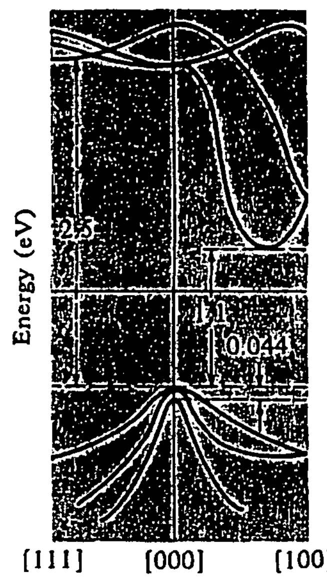
- KEY FEATURE
  - LATTICE CONSTANT MISMATCH (~ 4.2% Ge TO Si)
- EPITAXIAL POSSIBILITIES
  - COHERENTLY STRAINED GROWTH
  - UNSTRAINED (RELAXED) GROWTH





Si(Ge) BAND STRUCTURE





EFFECT OF STRAIN ON $Si_{1-x}Ge_x$ BANDSTRUCTURE

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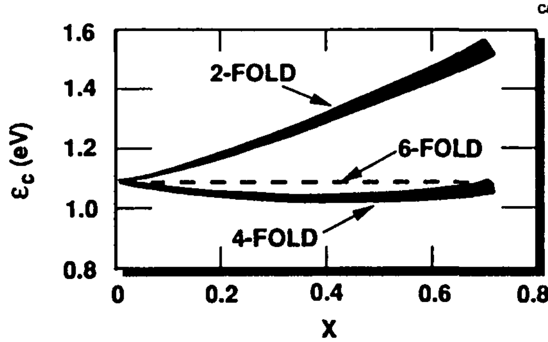
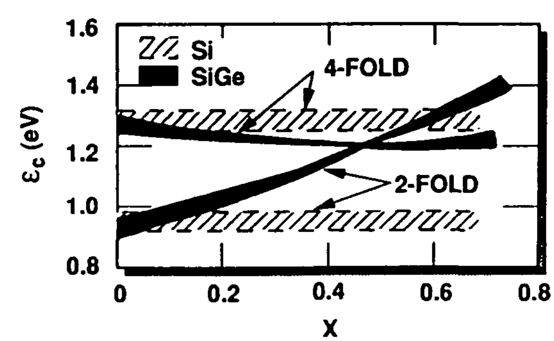
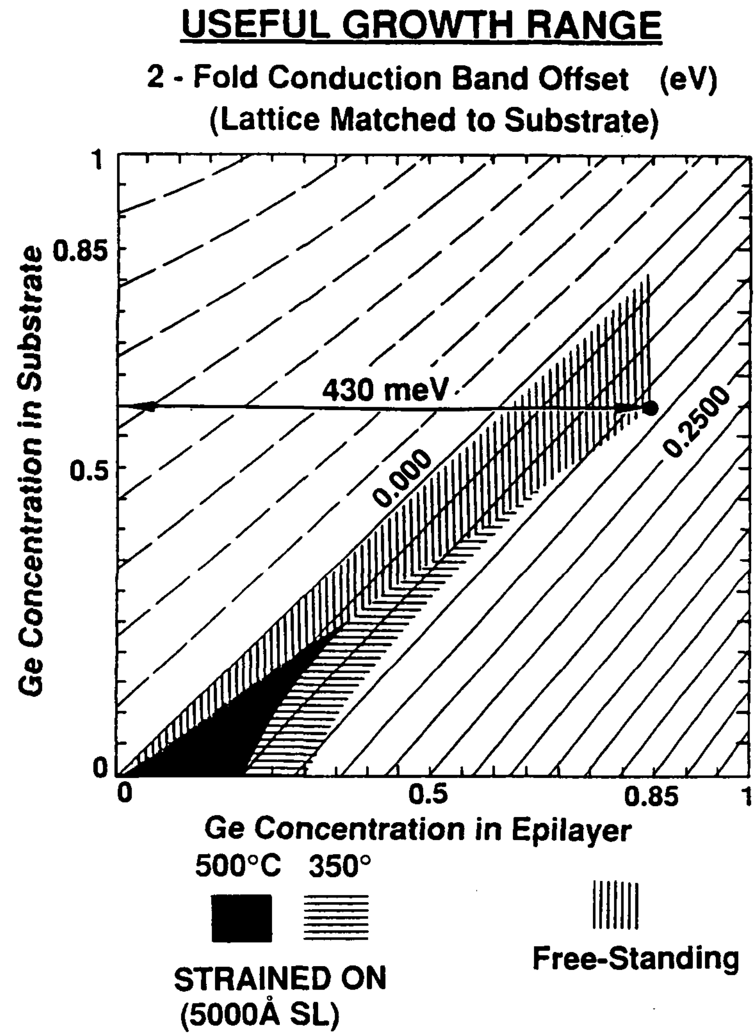
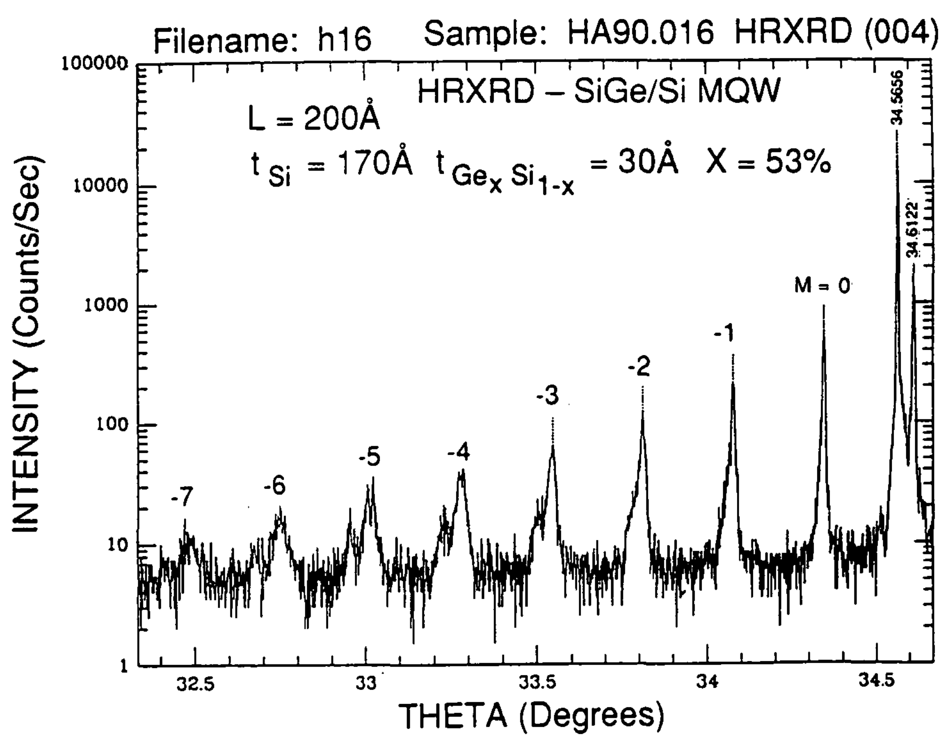
$Si_{1-x}Ge_x$ ON Si (100):

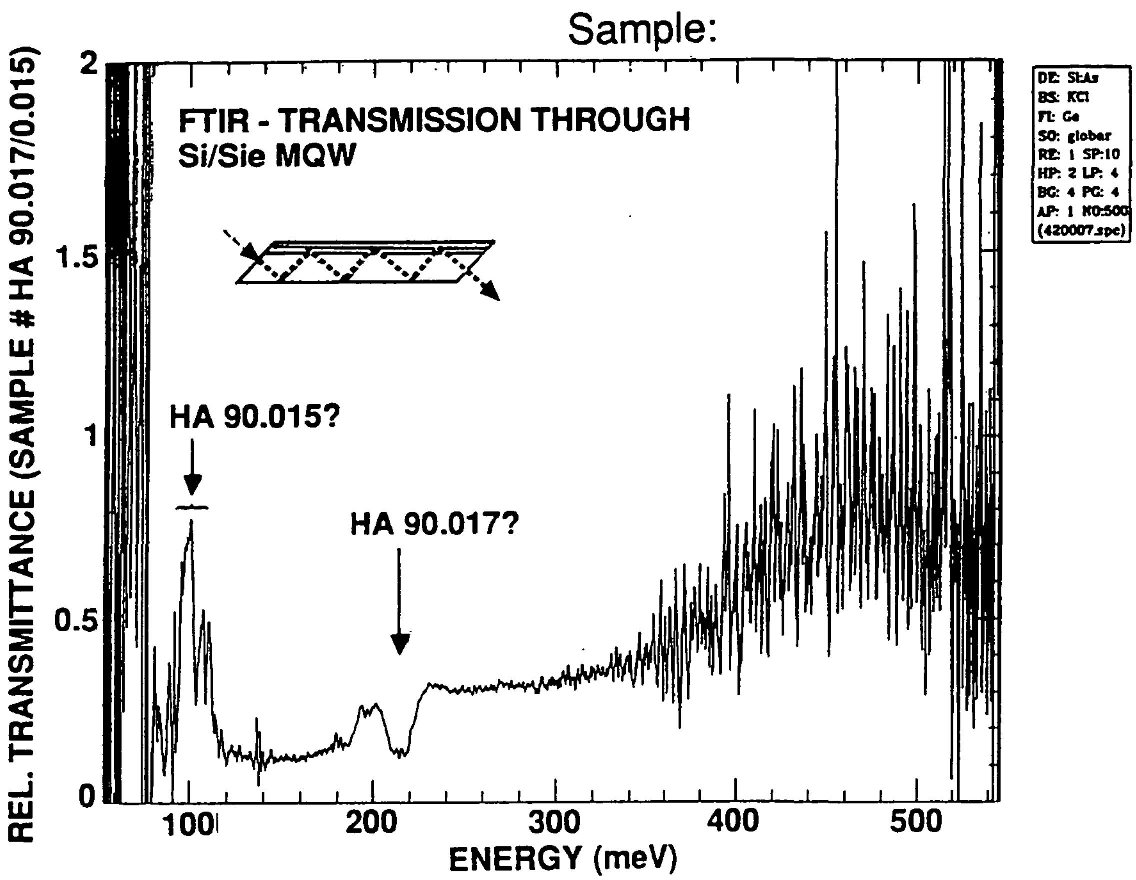


$Si_{1-x}Ge_x$ ON $Si_{0.5}Ge_{0.5}$ (100):




USEFUL GROWTH RANGE
2 - Fold Conduction Band Offset (eV)
(Lattice Matched to Substrate)
Ge Concentration in Substrate
Ge Concentration in Epilayer
430 meV
0.000
0.2500
500°C 350°
STRAINED ON
(5000Å SL)
Free-Standing


Filename: h16 Sample: HA90.016 HRXRD (004)
HRXRD – SiGe/Si MQW
L = 200Å
t_{Si} = 170Å $t_{Ge_x Si_{1-x}}$ = 30Å X = 53%
INTENSITY (Counts/Sec)
THETA (Degrees)
M = 0
34.5656
34.6122



SYNOPSIS - SiGe/Si MQW'S - (100) FILMS

	WELL	BARRIER	BUFFER	NON-PARAB.	MBE GROWTH
n-Type	Si	$Si_{1-X}Ge_X$	$Si_{1-X}Ge_X$(RLX)	WEAK	HARDER
p-Type	$Si_{1-X}Ge_X$	Si	Si(COH)	STRONG	EASIER

	DETECTS NORM. ALUM.?	8 - 12mm?	α RAIC$^{(CM^{-1})}$
n-(100)	NO	YES	~ 6000
n-(110)	YES	YES	~ 5000
n-(111)	YES	NO	~ 4000

SCHOTTKY BARRIERS ON Si AND Ge FOR SELECTED METALS (300K)

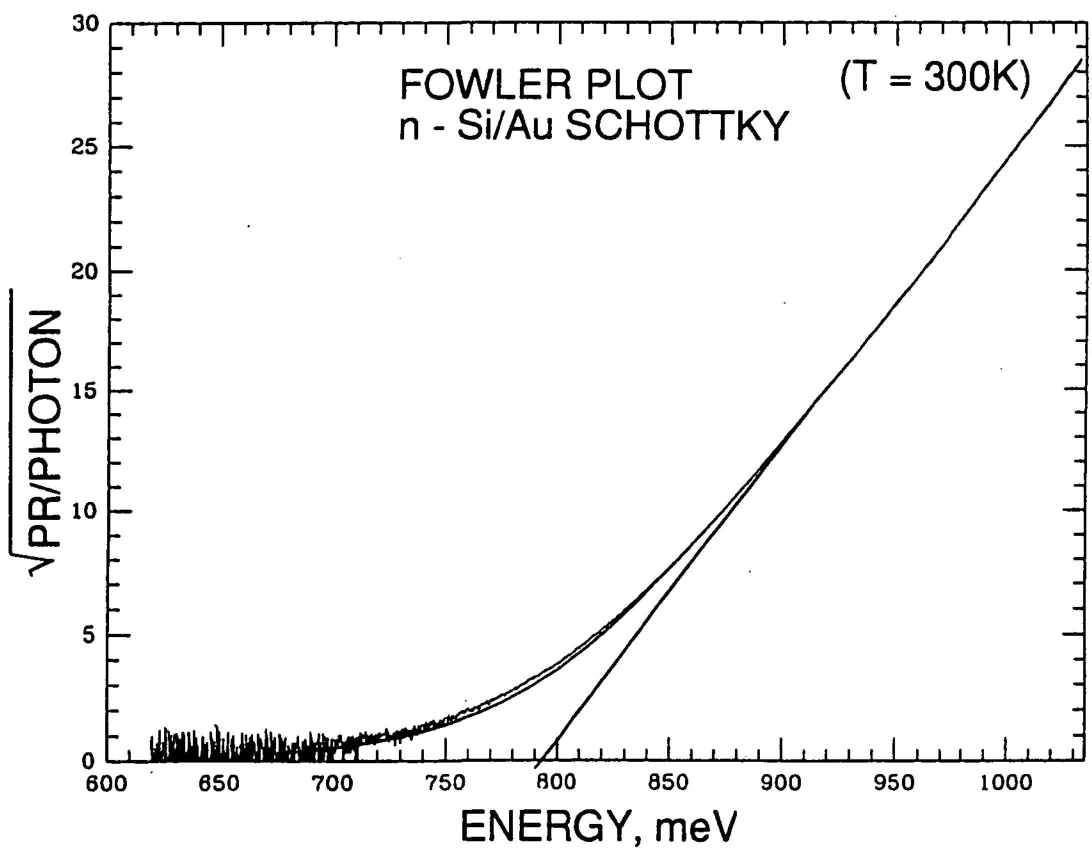
	Ag	Al	Au	Cu	Ni	Pt	W
(n) Si	0.78	0.72	0.80	0.58	0.61	0.90	0.67
(p) Si	0.54	0.58	0.34	0.46	0.51	-	0.45
(n) Gr	0.54	0.48	0.59	0.52	0.49	-	0.48
(p) Ge	0.50	-	0.30	-	-	-	-

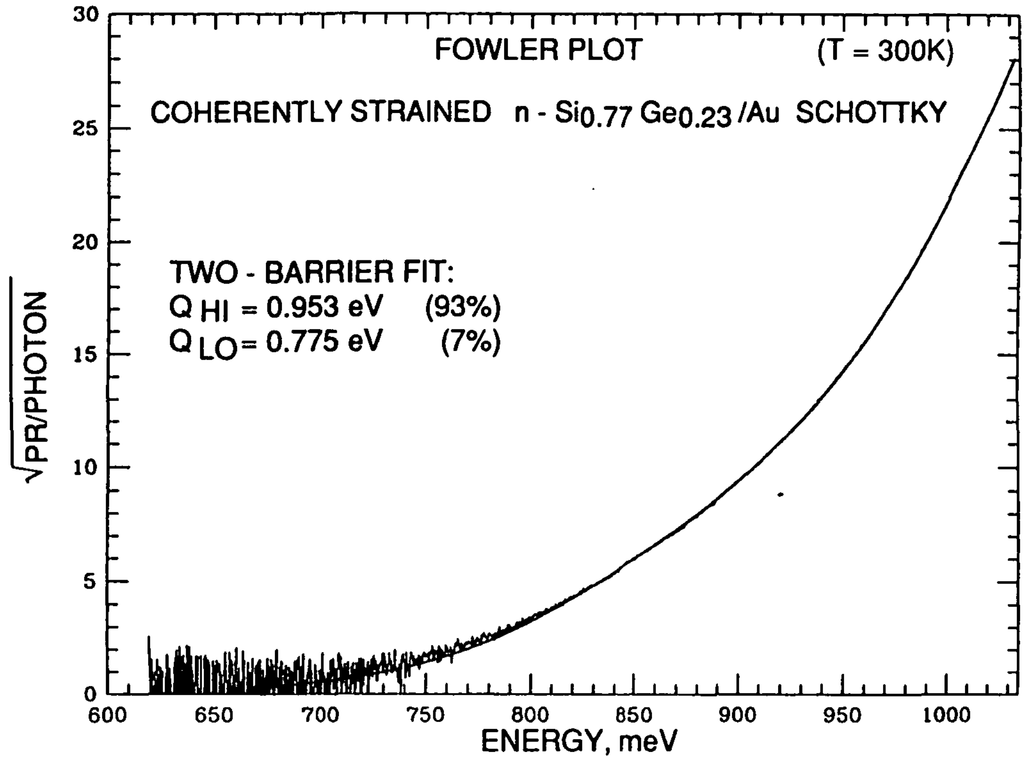
$\Delta Q_n >> \Delta Q_p$ IN MOST CASES

$\Rightarrow E_F^{METAL} \approx$ PINNED TO VALENCE BAND EDGE

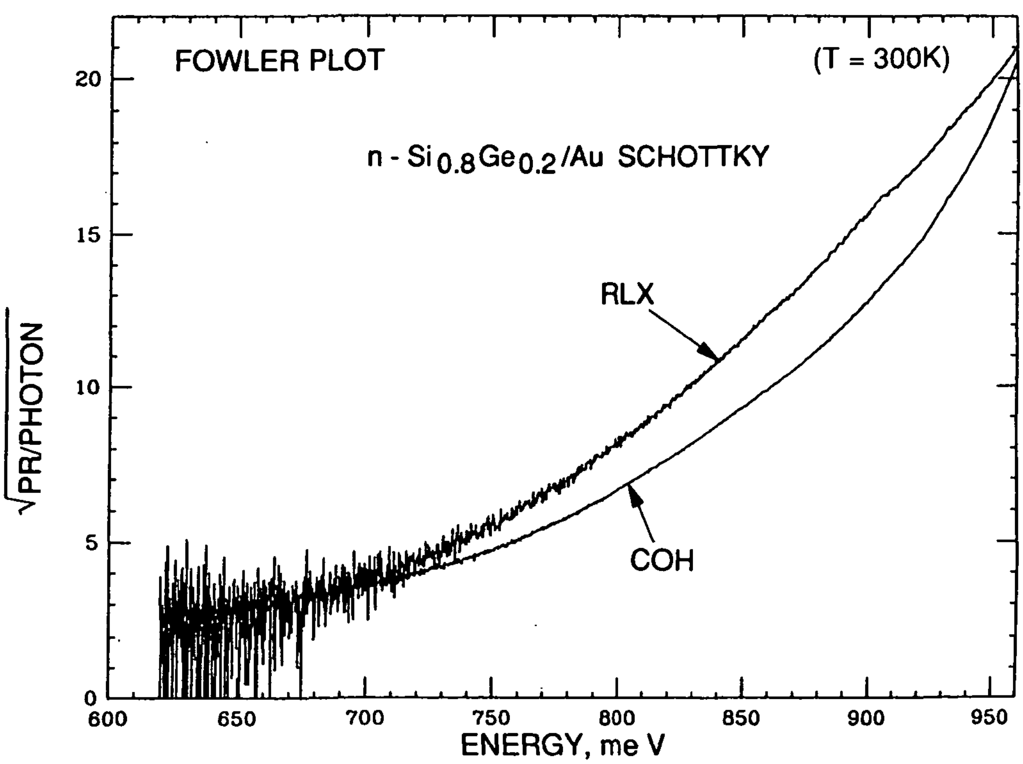
INTERPOLATE VALUES FOR UNSTRAINED $Si_{1-x}Ge_x$?

FROM S.M. SZE, "PHYSICS OF SEMICONDUCTOR DEVICES," WILEY, 1981, CHAP. 5





FOWLER PLOT
(T = 300K)
COHERENTLY STRAINED n - Si0.77 Ge0.23 /Au SCHOTTKY
TWO - BARRIER FIT:
Q HI = 0.953 eV (93%)
Q LO= 0.775 eV (7%)
√PR/PHOTON
ENERGY, meV



FOWLER PLOT
(T = 300K)
n - Si0.8Ge0.2 /Au SCHOTTKY
RLX
COH
√PR/PHOTON
ENERGY, me V

SUMMARY

- Si MBE ⇒ MULTILAYERS IN A Si-PROCESS - COMPATIBLE TECHNOLOGY
- BETTER "CONVENTIONAL" DEVICES POSSIBLE (E.G., Si:Ga IBC)
- NOVEL DEVICES POSSIBLE (MQW)
- SiGe/Si MQW ADVANTAGE: DETECTS NORMALLY INCIDENT LIGHT
- Si(Ge) STRAINED SCHOTTKY BARRIERS: INTERESTING PROSPECTS FOR DEVICES AND PHYSICS