Investigation of the impact of Ge-quantum well width in $Si/SiO_2/Ge/SiO_2/Pt$ resonant tunneling device (RTD) with NEGF formalism

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Outline

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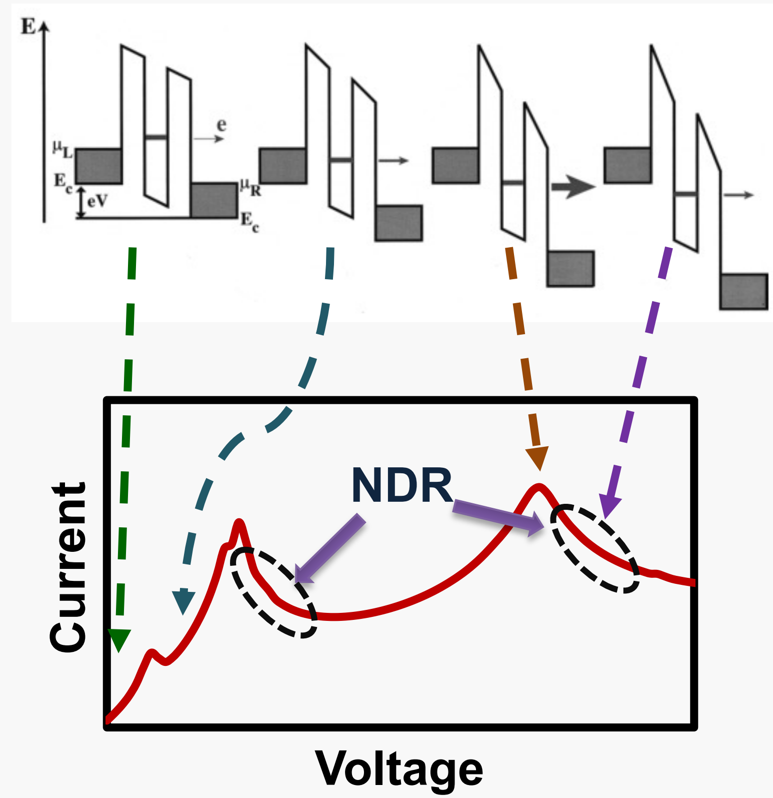
Resonant tunneling

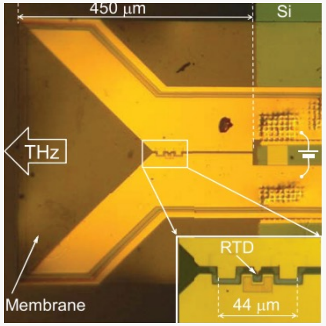
- In a double barrier structure, resonant tunneling occurs when the energy level of incoming electrons coincides with one of the quasi-bound states in the quantum well.
- RTDs exhibit negative differential resistance (NDR).
- The peak-to-valley current ratio (PVCR) is a figure of merit of RTDs.
- High PVCR $\Rightarrow$ better signal to noise ratio, which is particularly useful in oscillators.

Adapted from Encyclopedia of Physical Science and Technology, 3rd ed, 2003.



Schematic representation of resonant tunneling in a double barrier and corresponding I-V characteristics.

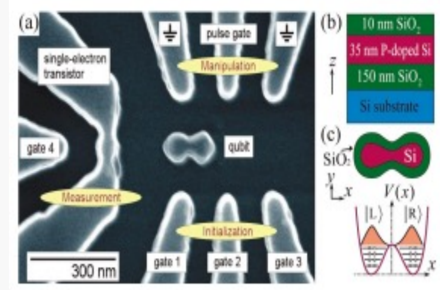
Resonant tunneling: Applications



Feiginov et. al., App. Phys. Lett, 2011.

THz oscillators

Qubit generation

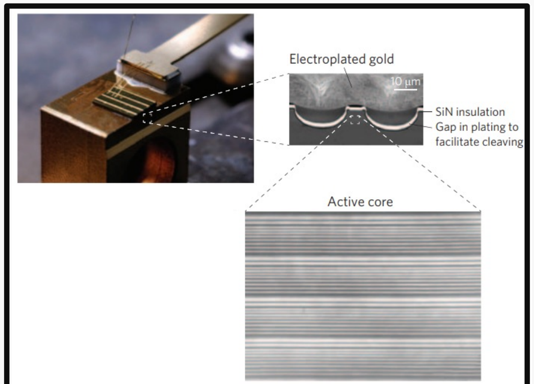


Gorman et. al., Phys. Rev. Lett, 2005.

THz imaging

Resonant Tunneling

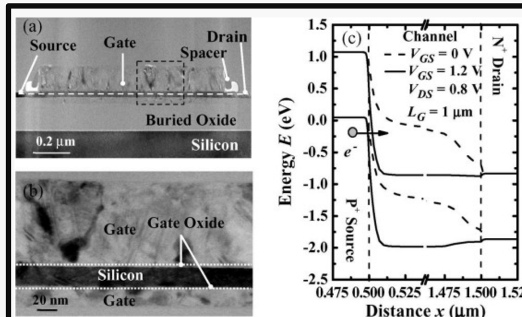
Double Quantum Dots



Yao et. al., Nat. Photon., 2012.

Optoelectr-onic devices

TFETs

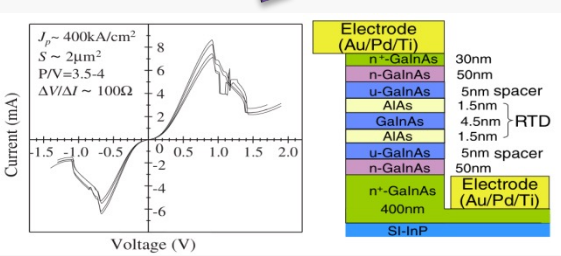


Guo et. al., IEEE Electron Dev. Lett, 2009.

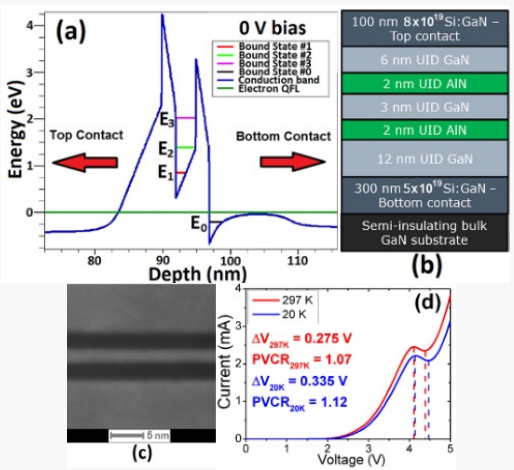
Devices fabricated so far…

- Low peak-to-valley current ratio (PVCR).
- Fabricated using III-V materials, particularly *InGaAs*, *InAlAs*, *AlN*, *GaN*, employing molecular beam epitaxy (MBE), metal-organic chemical vapor deposition (MOCVD) and so on…
- Si/Ge in contrast may provide cost effectiveness and simplicity in terms of fabrication.

MBE

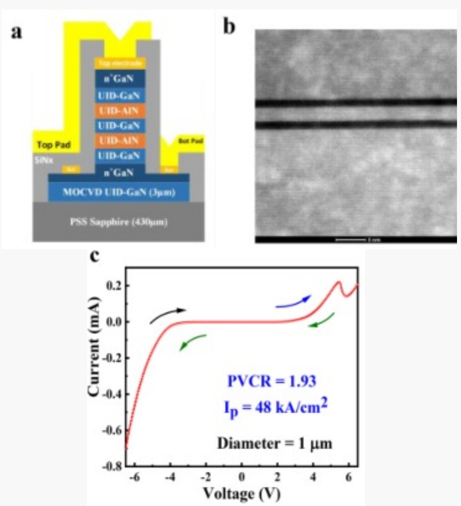


Asada et. al., Jap. J. Appl. Phys, 2008.
PVCR ~ 3.5-4



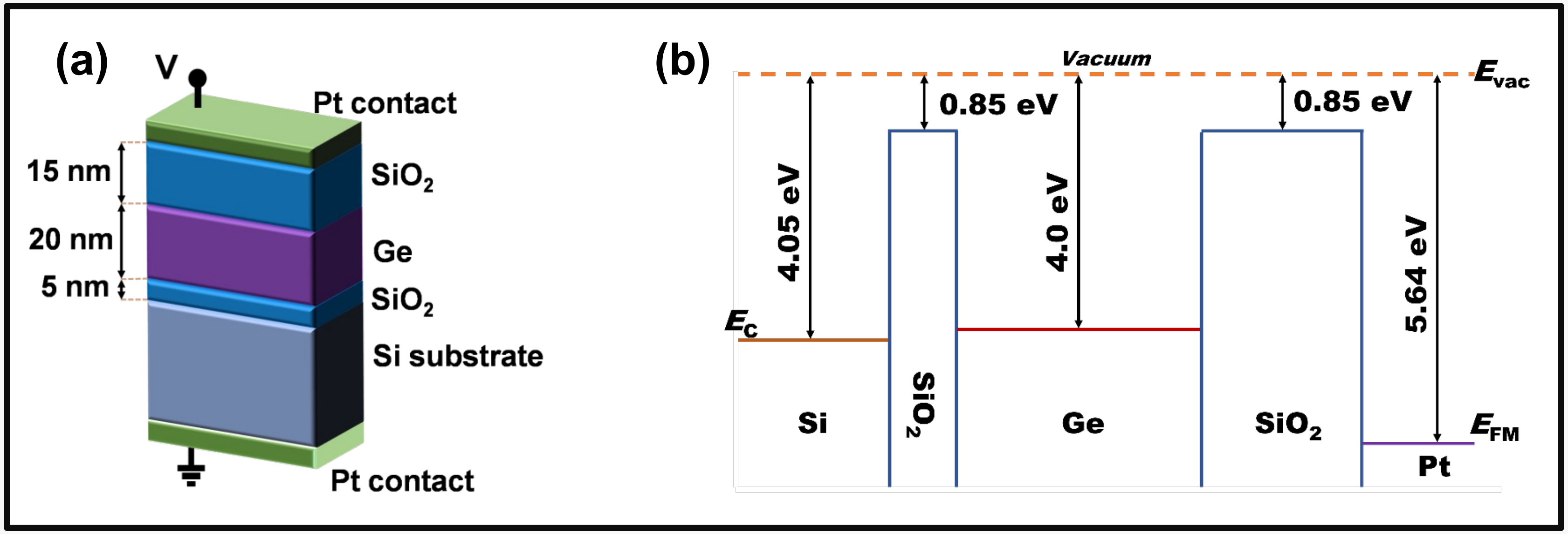
Growden et. al., App. Phys. Lett., 2016.
PVCR ~ 1.12

MOCVD



Zhang et. al., J. App. Phys., 2021.
PVCR ~ 1.93

Device schematic in this work

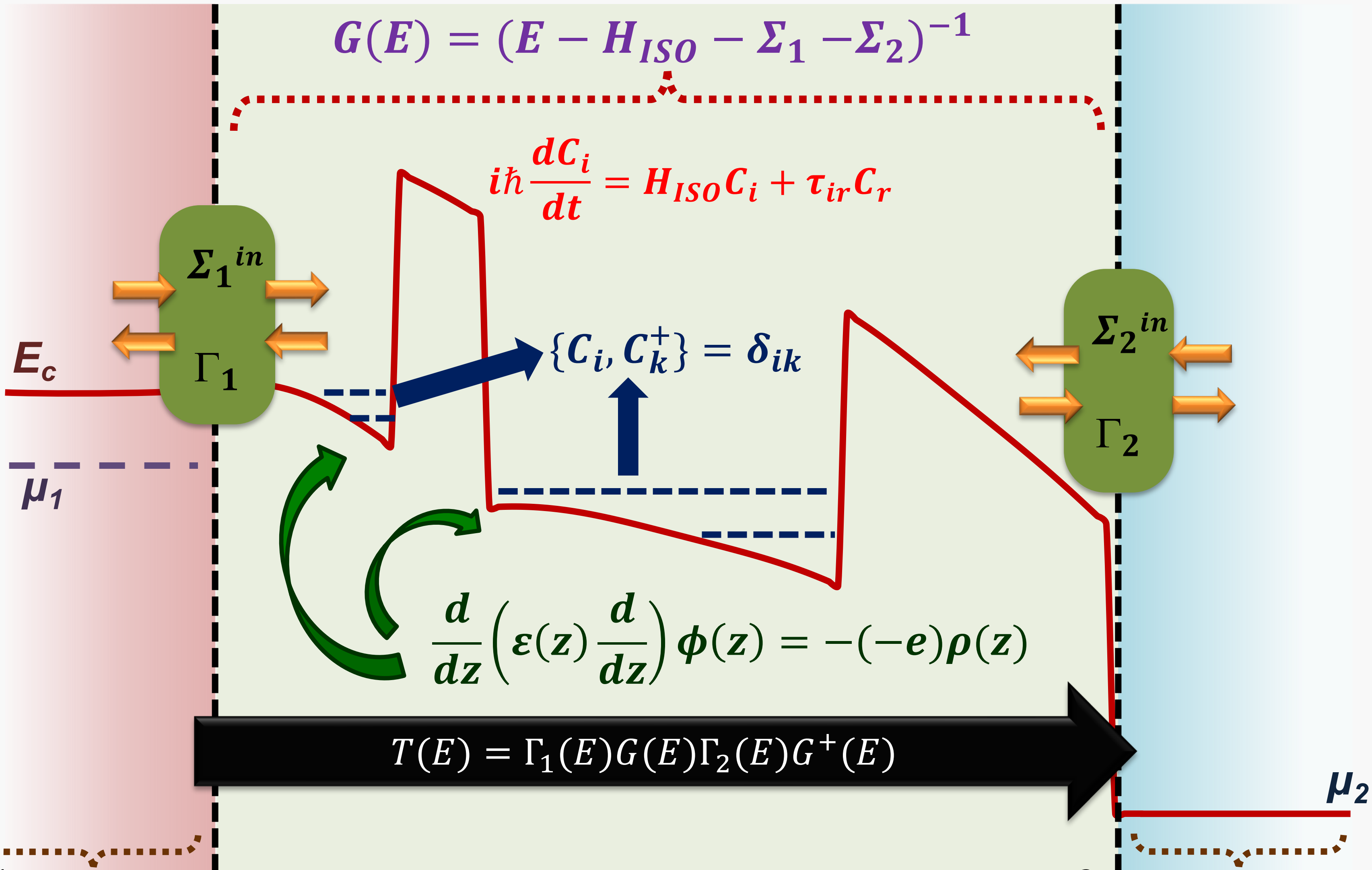


(a) Schematic of $Si/SiO_2/Ge/SiO_2/Pt$ resonant tunneling device. The Si substrate and top Pt contact act as reservoirs, source and drain, respectively.

(b) Bandstructure of the device considered, in equilibrium. The thickness of the low bandgap Ge-film in-between the barriers is less than its EBR (~25 nm) and therefore, it acts as a quantum well.

- ***Asymmetric barriers can provide technological flexibility in terms of fabrication in practice.***

Theoretical model



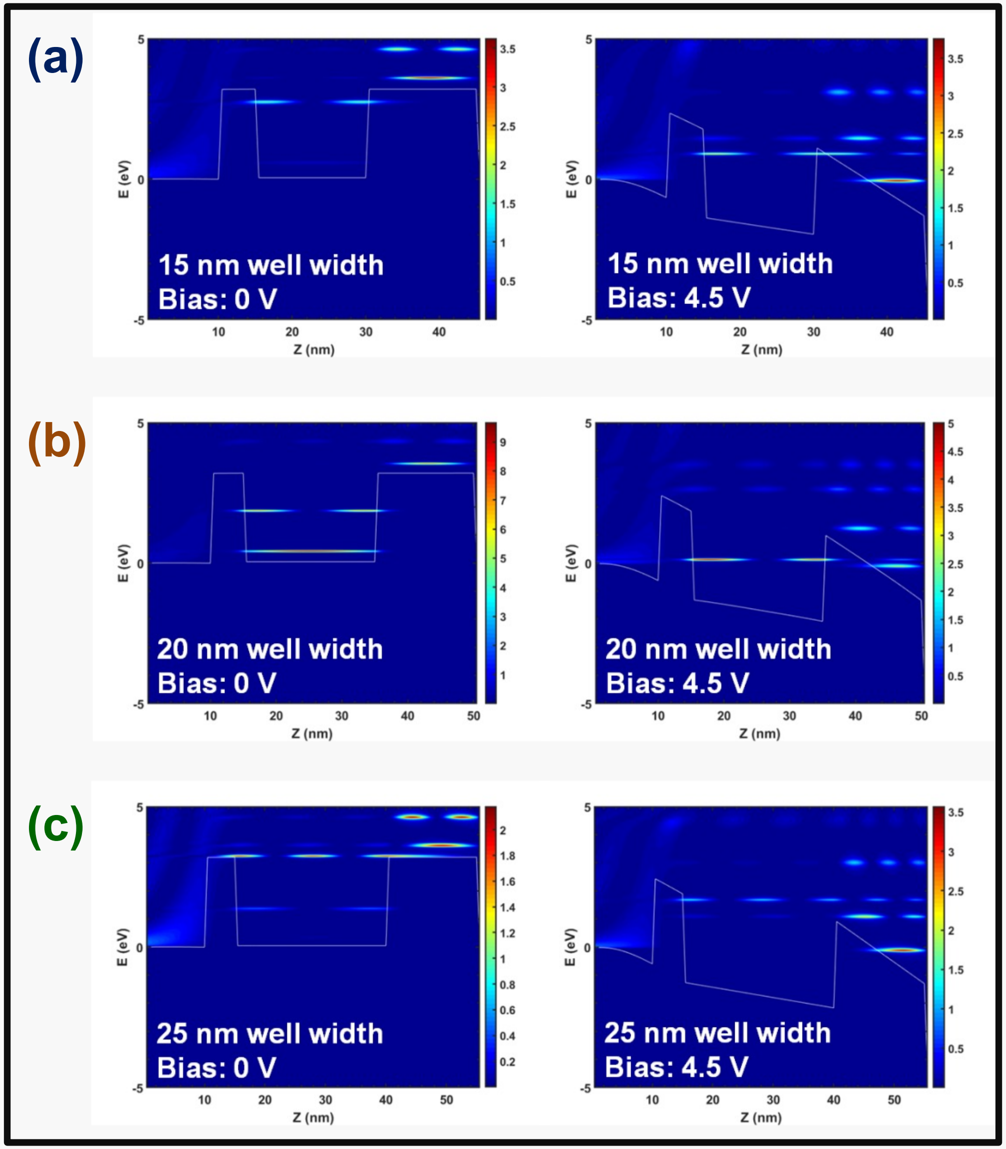
$$i\hbar \frac{dC^1{}_r}{dt} = H_{R1}C^1{}_r + \tau^*_{1i}C_i$$

$$i\hbar \frac{dC^2{}_r}{dt} = H_{R2}C^2{}_r + \tau^*_{2i}C_i$$

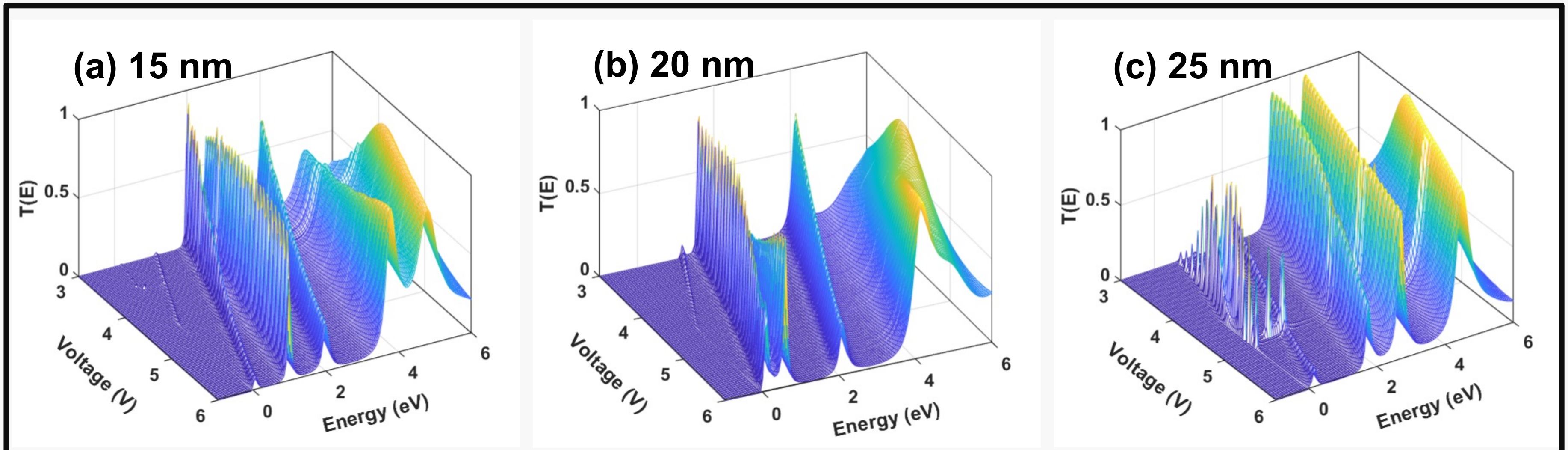
Results : DOS Plots

DOS plots for device with different Ge-quantum well layer widths, for zero and 4.5 V applied biases.
(a) 15 nm (b) 20 nm (c) 25 nm

- A wider Ge-quantum well layer allows for more number of eigenstates compared to a thinner well.
- Application of bias changes the shape of the quantum wells and consequently, the energy levels in them.
- The bias required for resonance also depends on the well width.
- Maximum level tuning is observed for the device with 20 nm wide well, when biased at 4.5 V.



Results : Transmission coefficient



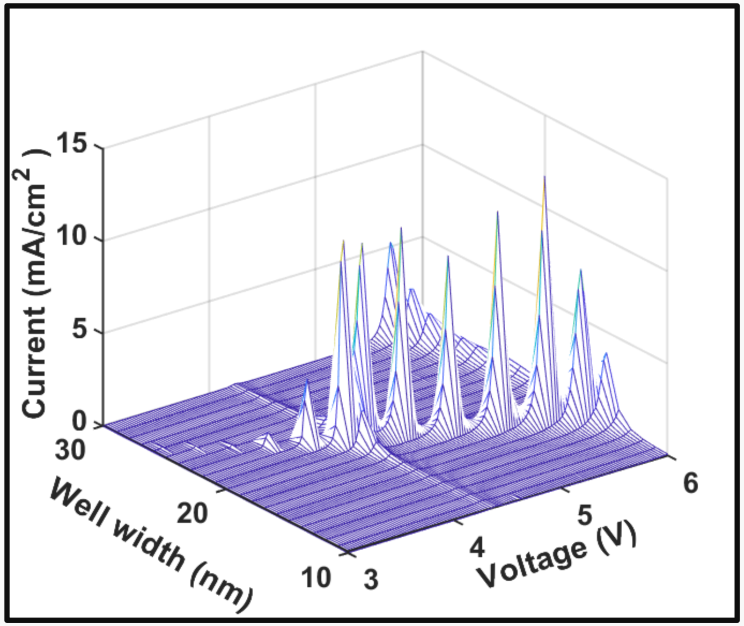
- Transmission coefficients for devices with Ge-quantum well widths of (a) 15 nm (b) 20 nm (c) 25 nm are considered.

- The increase in well width results in an increasing number of eigenstates.

- The decrease in well width leads to a sharper resonance corresponding to the decrease in broadening of energy levels.

- These two are counteracting phenomena and their combined effect leads to maximum tunneling currents in the device with ~20 nm wide quantum well layer.

Results : IV Characteristics



Current valley characteristics of the device obtained by varying the Ge-quantum well width, data summarized in adjacent table.

Well width (nm)	Resonance Voltage (V)	Peak current density (mA/cm^2)	PVCR
25	3.30	0.12	3.75
24	3.53	0.13	8.50
23	3.75	0.76	8.96
22	4.00	3.58	10.44
21	4.23	11.01	10.09
20	4.65	11.30	17.86
19	4.98	9.55	17.38
18	5.33	11.68	16.76
17	5.65	13.36	12.47
16	5.88	8.26	14.03
15	6.00	3.86	5.65

- A maximum PVCR of ~18 is obtained for a well width of 20 nm, corresponding to a peak current density of 11.30 mA/cm^2.
- Decrease in well width corresponds to a shift of current peaks to higher bias voltages.
- Current peaks are observed to reach a minima for increasing the well width beyond 22 nm.

Conclusions

- The variation of resonant tunneling current with applied bias and Ge-quantum well width at room temperature is investigated in detail. The results indicate that significant resonant tunneling requires higher voltages for lower Ge-well width.

- For reducing the Ge-well width from above EBR to a sub-EBR value, the PVCR exhibits a maximum value at a well width of 20 nm.

- The tunneling current peak reaches a maximum value of 13.36 mA/cm^2 for a well width of 17 nm, corresponding to a PVCR of 12.47.

- These values of PVCR are larger in order than conventional RTDs, at room temperature.

Acknowledgements

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- CRNN, C.U.
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THANK YOU!