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DESIGN AND SIMULATION OF SINGLE ELECTRON INVERTER FOR ROOM TEMPERATURE OPERATION

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In this paper, single electron inverter, for room temperature (300 K) operation has been designed and simulated in SIMON 2.0 software. The designed single electron inverter consists of two single electron transistors (SETs) connected in series, sharing common gate voltage. The calculated value of dot capacitance for room temperature operation is 7.750 × 10^{-20} F. The gate capacitance (C_G) is chosen half of this value i. e. 3.875 × 10^{-20} F for logic operation, while the source (C_{TS}) and drain (C_{TD}) tunnel junction capacitances are taken of equal value 1.936 × 10^{-20} F. The supply voltages V_{DD} and V_{SS} have been calculated from tunnel and gate capacitances and found to be +1.375 and -1.375 V respectively. The input voltage +0.4 V and -0.4 V are taken for high and low logic and are applied at common terminal of both the gates. The corresponding output voltages, measured at load capacitance are -0.658 V and +0.658 V respectively. In addition to room temperature, the truth table of inverter logic operation at 100K and 200K temperatures is also verified.

Keywords: Single Electron Transistor (SET), Single Electron Inverter, Single Electron Tunneling Devices, Transfer Characteristic, Room Temperature Operation.

1. Introduction

The single electron devices (SEDs) are being extensively studied as they provide high circuit density integration with low power dissipation and have good potential for various analog, digital and sensors applications [1]. Several circuits namely single-electron memories [2], inverters, pumps and logic gates [3-4] have been implemented using single electron transistors (SETs). There are various simulators, which support single electron circuits design such as MOSES, by Chen et. al. [4], SENECA by Fonseca et al. [5] and by Ancona [6]. In addition to these simulators, Wasshuber et. al. developed a GUI program SIMON for simulation of single electron devices and circuits [7-8]. SET based digital circuits can be implemented with both voltage as well as charge state logic (i.e. presence/absence of unit electron charge on the quantum dot). Design and fabrication of SEDs for room temperature operation are always preferred. Fukui et. al. designed a single electron inverter for operation below 4mK temperature [3]. Uchida et. al. propose a model for single electron transistor for operation at 4.2 K temperature [9]. In this paper a capacitively coupled single electron transistor (C-SET) based inverter for room temperature (300 K)

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operation has been designed in SIMON 2.0. Simulation procedure and results are presented.

2. Design of Single Electron Inverter

The circuit of SET inverter, designed in SIMON 2.0 is shown in the figure 1. SIMON 2.0 simulates the designed circuits using Monte Carlo-Master Equation (MC-ME) method. The designed SET inverter consists of two single-electron transistors in series sharing common gate voltage through two gate capacitors.
The various parameters of the inverter are derived on basis of following two assumptions:

(i) For the electron to hop on the central island, its charging energy should be

$$E_C = \frac{e^2}{2C_\Sigma} \qquad (1)$$

(ii) and to prevent undesired tunneling, charging energy must be greater than thermal energy i.e.

$$E_C >> k_b T \qquad (2)$$

Where
K_b: Boltzman's Constant (1.381×10^{-23} J/K)
T: Temperature (K)

In order to avoid thermally-induced random tunneling events, the criteria mentioned in equation (2) can be modified into following inequality [10]:

$$E_c = 40K_bT \qquad (3)$$

After combining equations (1) and (3), the dot capacitance can be calculated as follows:

$$C_\Sigma = \frac{e^2}{40\,X\,2k_bT} \qquad (4)$$

Where
C_Σ: Total capacitance of each of two transistors in series.

$C_\Sigma = C_g + C_{TS} + C_{TD}$

The calculated value of C_Σ is 7.75 X 10^{-20} F for room temperature operated SET.

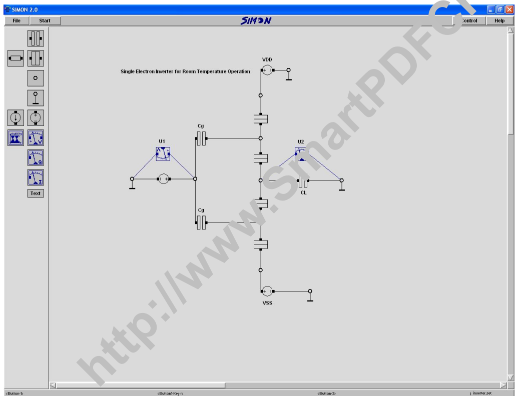

Fig. 1. Snap shot of designed single electron inverter in SIMON2.0

To make SET as logic, the following condition should satisfy [9]:

$$\frac{C_g}{C_\Sigma} \geq 0.5 \qquad (5)$$

After applying this criterion we get C_g=3.875 X 10^{-20} F and $C_{TD} = C_{TS}$ = 1.936 X 10^{-20} F. V_{DD} and V_{SS} voltages values are derived from coulomb blockade region in stability plot. Here symmetric source and drain tunnel junctions are assumed i.e. $C_{TD} = C_{TS} = C_T$. The drain and source voltages, defined by the SET device parameters are as follows [10]:

$$V_{island1} - \left(\frac{e}{2C_\Sigma}\right) \leq 0$$

$$V_{DD}\left(\frac{C_g + C_T}{C_\Sigma}\right) \leq \frac{e}{2C_\Sigma}$$

$$V_{DD} \leq \left(\frac{e}{2\left(C_g + C_T\right)}\right) \qquad (6)$$

Putting the values of capacitances in equation (6) will give V_{DD} = 1.375V and V_{DD} = $-V_{SS}$. The values of parameters, used in design of inverter circuit are summarized in the table 1.

Table 1: Calculated parameter values of SET inverter used in SIMON 2.0.

Parameter	Value
V_{DD}	1.375 V
V_{SS}	-1.375 V
C_g	3.875×10^{-20} F

$C_{TS}= C_{TD}=C_T$	1.936×10^{-20} F
C_L	1.936×10^{-20} F
T	300 K

In SIMON all input voltage values are entered with respect to time. The input logic/voltage for inverter is applied on the gate, which is designated here as U1 and it is piecewise continuous. The output voltage at load capacitance is represented as U2. The input U1 switches between +0.4V (High Logic) and -0.4V (Low Logic) and the corresponding output U2 is measured at load capacitance.

3. Simulation Results and Discussion

The designed single electron inverter circuit is simulated in SIMON. The simulation results for 300 K temperature are shown in figure 2.

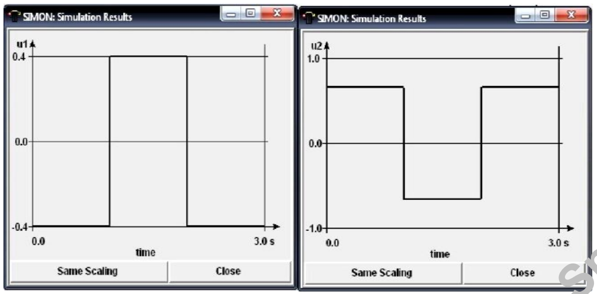

Fig. 2. Simulated input and output voltage characteristics of inverter at 300K.

When low input (U1) of -0.4V is applied, the corresponding high output (U2) of 0.658 V is obtained at load capacitance and for high input of 0.4 V, the corresponding low output is -0.658 V. From figure 2 it is clear that I/P logic sequence [010] provide O/P [101], which confirms the inverter operation at 300K. The transfer characteristic of inverter for I/P voltage range [-0.4V, +0.4V] is plotted in figure 3.

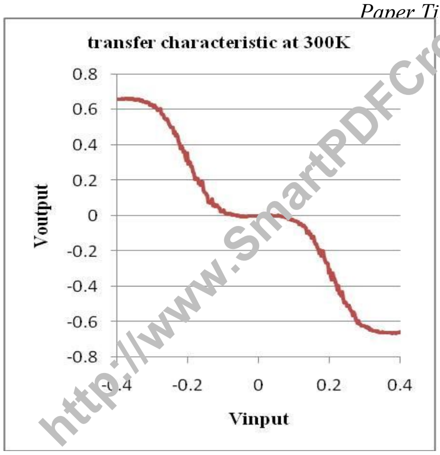

Fig. 3. Transfer characteristic of inverter at 300K.

The simulation results of the same circuit at 200K shows high output 0.667 V and low output -0.667 V corresponding to -0.4 V and +0.4 V I/P voltages respectively. This circuit was also simulated at 100K, then low input of -0.4 V provides high output of 0.668V and the corresponding output of high input of 0.4 V is low output of -0.668 V. The transfer characteristics of inverter circuit at 100, 200 and 300K are plotted in figure 4. These plots verify the inverter operation of the designed circuit at these temperatures.

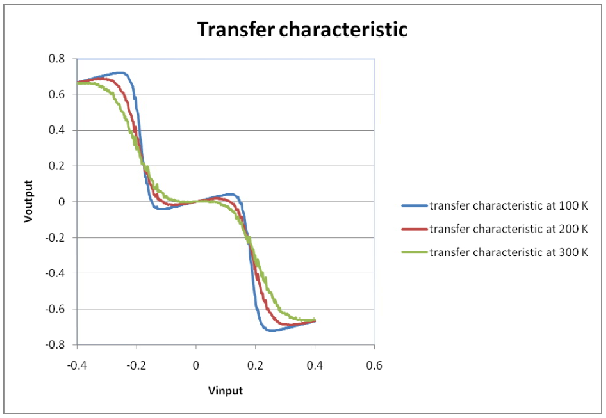

Fig. 4. Transfer characteristic of single electron inverter at 100, 200 and 300K temperatures.

Conclusions:

The single electron inverter for room temperature (300 K) operation has been designed and simulated with very low values (±0.4V) of input logic voltage values. Device and bias parameters for 300 K operation have been calculated. The inverter operation of the designed circuit at lower temperatures i.e. 100 and 200K has been verified.

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