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Physica C 341–348 (2000) 1607–1608

PHYSICA C

www.elsevier.nl/locate/physc

Superconductor based neuron single electron transistor

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We have proposed a new functional superconductor single electron transistor called neuron superconducting single electron transistor (Neuron – SuSET), which simulates the function of biological neurons. The new transistor is capable of executing a weighted sum calculation of multiple input signals and threshold operation based on the results of the weighted summation, The basic structure and the variable threshold characteristics of the Neuron – SuSET are described based on the semiclassical model.

1. INTRODUCTION

Neuron – SuSET, which is proposed for ULSI, is the enhancement in the function of an elemental transistor. Because the superconducting energy gap, in contrast to the Coulomb blockade, is not smeared by the finite temperature, the noise limited charge sensitivity of the Neuron – SuSET operating near the threshold of quasiparticle tunneling, can be considerably higher than that of a similar transistor made of normal metals or semiconductors [1]. The pair contribution is suppressed, either by the application of an external magnetic field or because $E_J < k_BT$ so that there is no pair coupling.

2. STRUCTURE AND PRINCIPLE

The equivalent circuit of the structure of a Neuron – SuSET is schematically illustrated in Fig.1. Every MTJ consists of the structure of C – axis oriented superconductor (YBCO) – barrier (PBCO) – superconductor (YBCO). The superconducting single electron transistor (SuSET) which consist of two MTJs in series is coupled to the controlled multi – gate electrodes G_i ($i = 1,2,\ldots,n$) by the capacitances C_{gi} ($i = 1,2,\ldots,n$) and C_f in series. C_{gi} is the capacitance between the controlled multi – gate (G_i) and the floating gate (F), C_f is the capacitance between the floating gate (G) and the central island (C). C_s, C_d and G_s, G_d are the junction capacitance and the tunnel conductance of the MTJ_s and MTJ_d at the source side and the drain side, respectively. V_d, V_s are the junction voltages. All voltages are with respect to ground. Q_F and Q_C are the charges on the floating gate (F) and the central island (C). Neuron – SuSET is driven by ideal constant voltage sources V_{DD}, V_{SS}, V_{GG}. In this paper, the state of each MTJ in the Neuron - SuSET is fully characterized by the junction voltage, which is a classical variable. Considering charge conservation on the central island (C) and the floating gate (F), and applying the Kirchoff's voltage law for the circuit loops, one can write out the junction voltages in terms of the Q_C and Q_F. The thickness of the YBCO central island and PBCO barrier is fixed at 150 and 20 nm. $C_d = C_s = 1\ C_0$, $G_d = G_s = 10\ G_0$ when the junction area of MTJs equals to 30 nm × 30 nm estimated [2]. $C_0 = 10^{-18}$ F, $G_0 = 10^{-6}$ (1/Ω).

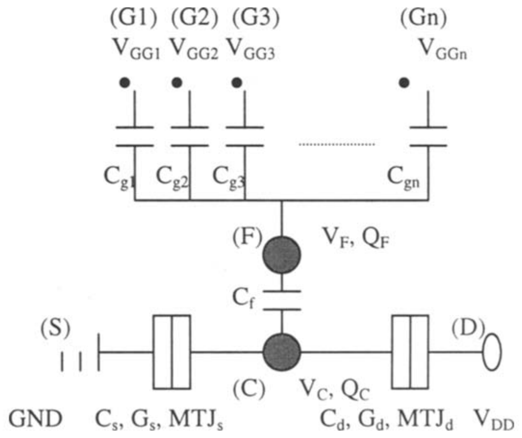

Fig. 1 Equivalent circuit of Neuron – SuSET

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PII S0921-4534(00)01467-2

The floating gate voltage V_F is obtained based on the relationships of the charges on the MTJ_d and the MTJ_s, the floating gate capacitance C_f, and the control capacitances C_{gi}.

$$V_F = \frac{Q_F + C_f V_s + \sum_{i=1}^{n} V_{GGi} C_{gi}}{C_f + \sum_{i=1}^{n} C_{gi}} \qquad (2)$$

One of the most important features of the Neuron – SuSET is clearly expressed in (2). The V_F is determined as a linear sum of all input signals weighted by the capacitive coupling coefficients. When V_F is smaller than the threshold voltage V_{th} of the transistor as seen from (F), the Neuron – SuSET is off. When V_F exceeds V_{th}, the transistor turns on.

3. VARIABLE THRESHOLD

If the two input - gate Neuron – SuSET is regarded as a regular SuSET where gate (G1) is the signal input terminal and gate (G2) is the terminal

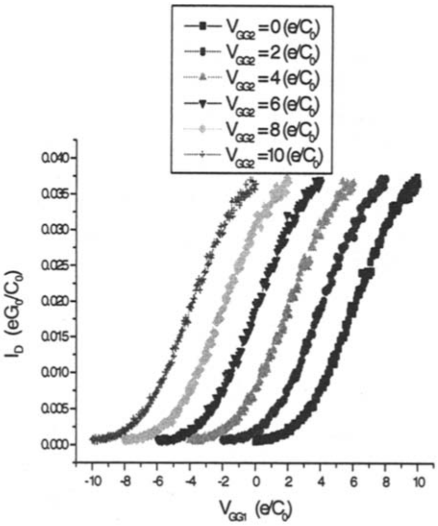

Figure. 2 Drain current – gate voltage curves of a variable threshold transistor for a two input gate Neuron – SuSET

for threshold voltage control, then the apparent threshold voltage of the transistor as seen from gate (G1) is given by

$$V_{th}^{1} = \frac{(C_f + \sum_{i=1}^{n} C_{gi})V_{th} - Q_F - C_f V_s}{C_{g1}} - \frac{C_{g2}}{C_{g1}} V_{GG2}$$

This threshold voltage can be arbitrarily changed by the control signal V_{GG2} (see Fig. 2). This is the concept of so-called variable threshold Neuron – SuSET, one of the simplest but most useful applications of Neuron – SuSET. Fig. 2 is obtained by the Monte Carlo simulator under the conditions: T = 18.5 K, $C_d = C_s = 1\ C_0$ $G_d = G_s = 10\ G_0$, $C_f = 0.1\ C_0$, $C_{g1} = C_{g2} = 0.5\ C_0$, V_{DD} = 24 mV, YBCO energy gap voltage at 0 K $2\Delta(0)/e$ = 64 mV, $C_0 = 10^{-18}$ F, $G_0 = 10^{-6}\ 1/\Omega$.

4. CONCLSION

Variable threshold characteristics of Neuron – SuSET has shown the feasibility that it can play an essential role in the implementation of the superconducting single electron multivalent logic circuits There are direct consequence of the operation principle of Neuron – SuSET in which weighted summation of multiple input voltages are performed via the capacitance coupling effect, resultant charge sharing among a number of capacitors and the Coulomb blockade effect of single electron systems.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 69890224, 69671005) and Shanghai AM Foundation (No. 98009).

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