SINGLE ELECTRON TRANSISTOR TECHNOLOGY BASED ON-CHIP IMPLEMENTATION OF SMOKE DETECTION ALARM FOR RESIDENTIAL SECURITY APPLICATION

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Abstract

The next generation electronic industry shows infinite scope of excellence starting from the cutting edge tools of massive industrial applications, war front technological support, health appliances, space applications and consequently offers unlimited cost effective consumer electronics for daily life uses. The quest for incorporating higher number of applications in one easy accessible, portable and smarter platform has paved the path of nanotechnology in contemporary consumer electronics in every sphere of life. Now societies are quite concern about security measures adopted so far in residential buildings, offices, school-colleges, owing to the fact that with modern technological support no life should be vulnerable to fire like hazards. But statically these precautionary systems are much expensive. In such circumstances the authors here tender to design a novel low power consuming, economical nano device smoke detector alarm to be incorporated in residential security systems.

Keywords: *Single Electronic Transistor, Coulomb Blockade, Tunneling Effect, and Nanoscaled devices.*

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1. INTRODUCTION

The post CMOS era envisaged that Scientists emphasized on developing new technologies where devices can be scaled down to nanometer range to cope up with the increasing demand of low power consuming and high integration density devices to meet the current needs [1-5]. Amid the newly invented technologies, Single Electron Device (SED), Carbon Nanotubes, Rapid Single Flux Quantum (RSFQ), Resonant Tunneling Diodes (RTD), and Magnetic Spin devices [6-11] indicated impressive results. Since then, research on these technologies created enormous hope. Among all others researches, Quantum Electronics and Single Electronics are mostly accepted to replace the present CMOS technology in realizing much scaled down devices. But failings of the quantum effects due to physical limitations emphatically weakened the idea to incorporate quantum effects for VLSI in the post CMOS era. Meanwhile, Fulton and Dolan in 1987 empirically demonstrated the first Single Electron Transistor (SET) charging effects in small tunnel junctions successfully [12]. But it took several years to further extend this technological research. Present day e-beam lithography technique has augmented the feasibility of basic physics of Single Electron Tunneling that is incorporated to design future low power consuming nano-scaled Single Electron Circuits. The development made so far in SET technology is divided in: - (i) Device Research that covers the vast and matured area of device fabrication related technical studies. Scientists all over the world has contributed largely in this category; and (ii) The Application of SET devices for various purposes that can be included in daily life; it is a different and completely new aspect to explore but only a little has been achieved in this category. Now, very few research attempts are reported so far to mold SET technology in a CMOS-like design style by realizing new SET based circuits that are truly identical to MOS circuits. It should be noted that SET is at its best only if its unique characters are explicitly utilized at all design levels, i.e., device, circuit and system which implies that SET's distinctive features needs to be explored and utilized fundamentally. In the subsequent sections we have demonstrated a smoke detection alarm using SET technology.

1.1 A Brief View of SET Technology

The unmatched features of single electronics will create a new horizon that is expected to rule the future electronics industry at least for the next century. In present context, we have emphasized in realizing fast switching, low power and less space consuming SET based logic circuits to substitute the conventional CMOS circuits as SET appears better candidate for the survival of the fittest in modern electronics.

Basic operations of tunneling junction in SET are depicted in the Fig 1. As an electron progresses toward 'A' and a pulse greater than 5mV is provided i.e., if Φn-1>5mV is applied, the electron becomes capable to cross tunnel junctions (J1 and J3) to ('C' or 'E'). This entire tunneling phenomena is based on the Coulomb energy [Ec=e2/(2C)] + applied energy. Summation of both these energy has to be far above the potential height of the barrier energy of junction(s) (J1 or J3). Following this principle, the electron moves the path 'QRST' or 'QRUV if the signal Xi>5mVand the corresponding total energy (i.e. Coulomb energy plus applied energy) is greater than static potential junction energy of J2 (or J4) [13-20].

SETs are built by coupling two tunnel junctions in series. The two tunnel junctions make a "Coulomb island" where electrons can only enter by tunneling through one of the insulators. This device is quite similar to the structural point of view of a FET having three terminals i.e., both the outer face terminal of each tunnel junction, and a "gate" terminal. The gate terminal remains capacitatively coupled to the node between the two tunnel junctions. The capacitor acts like a third tunnel junction, but its thickness is more than the others restricting other electrons to tunnel through it. Basically the capacitor serves as a process of setting the electric charge on the Coulomb Island [21-23]. A Simple SET circuit is shown in Fig.2.6 below along with its complete schematic in Fig.2.

For real time applications it is utmost necessary to design SET based various logic gates. A small number of research publications in this category have been reported so far [24-26]. These SET based logic gate designs have not only attracted us, further it motivated us to design a single electron device based smoke detector alarm that can be incorporated in residential as well as commercial buildings for security purpose of the people in general. The design specification is kept simple considering the cost and portability of the proposed system.

1.2 Commercial Smoke Detectors

Available commercial smoke detectors are either conventional or analog in type, and are connected to security monitoring systems or fire alarm control panels (FACP). These most common type of detectors usually cost a lot more than a household smoke alarms. Thus such smoke detectors yet not are largely put up in every residential property. They exist mainly in most commercial and industrial houses and few in commercial high rises, ships and trains. As per the report published by World Fire Safety Foundation in June'2013; it questioned the validity of smoke detectors of the most pioneering countries including USA and Australia. It revealed that even after huge expenses in such security systems the National Fire Protection Association estimates that in United States itself, nearly two-thirds of deaths are caused from home fires occur in properties without any smoke detectors or non-working smoke alarms/detectors [27-30].

The third world countries including India lags far behind in obtaining such security systems as it is beyond the cost calculations of a general people.Also the conventional smoke detectors are quite large in size and to large extent they are quite power hungry devices and thus it is needed to be replaced by new technology which will be much more efficient, comfortably portable and low power consuming. Thus the authors here deliberately attempted to design nano scaled Single Electron Transistor based smoke detectors for residential applications. A schematic of the proposed smoke detector is depicted in the following Fig.3.The design considerations are made low profile to do justice with the economical constraints.

2. CIRCUIT DIAGRAM OF THE PROPOSED SET BASED LOGIC CIRCUIT OF SMOKE DETECTOR

Fig.4 is a detailed circuit realization of Single Electron Transistor based Smoke Detector.

2.1 The Modus Operandi of the Circuit Operation

The circuit consists of two highly responsive smoke detectors marked as input sensors in Fig.4. On the other side of the circuit one Sprinkler and one telephone dialer is attached to follow the resultant operations of the circuit. Either any or all smoke detectors detect any amount of smoke the SET based logic circuit is activated and the Sprinkler is triggered. An automatic call on facility telephone is kept standby to signal the fire department personnel in emergency fire break out.

$\overline{D1}$ and $\overline{D2}$ receive active-low outputs from two smoke detectors initially. As the detectors are initialized i.e., during detection of smoke electron tunnels in and after considerable amount of charge is dissipated to the other end of the circuit; i.e., at the Sprinkler coupling end denoted as $\overline{SPK}$; it becomes active high. Otherwise, $\overline{SPK}$ is always having active-low input to the Sprinkler. The tunneling of electrons beyond Coulomb Blockade persists until $\overline{D1}$ and $\overline{D2}$ obtains active-low signal. Moreover the telephone dialer namely $\overline{DIAL}$ is associated to the external leads of the circuit which is presumed to be kept active-low during the normal operation of the circuit. Once activated it turns active-high and until the fire fighter personnel picks up the message. Thus the signals $\overline{D1}$ and $\overline{D2}$ is ORed with $\overline{SPK}$ whereas $\overline{D1}$ and $\overline{D2}$ is ANDed with $\overline{DIAL}$.

The empirical design is tested in Monte Carlo based simulation platform. The results obtained are of better acceptability and the process has greater proximity in being realized in an on-chip platform. Detailed analysis of the circuit is not shown here due to space limitations but the vital statistics are put down in the following sections to study its effectiveness in the post CMOS era.

2.2 Comparative Study of CMOS based Smoke Detector Circuit and SET based Smoke Detector Circuit

Table.1 represents the comparative study of the smoke detector circuit considering that the most efficient fabrication technology is adapted for both Transistor-Transistor Logic and Single Electron Transistor Logic. Further, in both the cases simplicity is given the first criteria to make the circuit cost effective.

Study revealed that in all circumstances the SET based Smoke Detector Circuit possess greater acceptability than conventional CMOS based circuits. Our proposed SET based system is much less power consuming but can provide result at a quicker speed. Thus a very high-speed computation is certainly attained with this design newly proposed SET configuration. The power dissipation for switching a single bit is of few μW which is considerably small when compared to conventional devices. It has higher prospect of providing much more component density thereby reducing the future IC sizes. Besides, other phenomenal distinctiveness SET circuit is quite faster than any conventional CMOS based circuit.

Table -1: SED vs. TTL

Sl. No.	Circuit Name	Propagation Delay time / Gate	Faster times	Power dissipation / Gate	Consume Power
1	TTL gates	12 ns	1	0.01 / 10-12 mW	1
2	SED gates	6 ns	2	~1μW	10^3

3. CONCLUSIONS

The fundamental concept of using CMOS technology is put on hold here to explore the robustness of SET in designing commercial and user friendly circuits. It revealed that the performance of SETs is absolutely superior compared to the Field-Effect Transistors due to their compact size. Other remarkable outcomes compared to CMOS circuits are low energy consumption, high sensitivity, and higher operating speed, simplified operational principle for simple circuit and high input impedances and low voltage gain. SETs are also extremely sensitive to random background charges. Owing to such, SETs have already replaced the decade old FETs in many real time applications where low output impedances and large voltage gain is indispensable. Thus undoubtedly SET stands as the best competitor in the next generation electronics beyond anyone’s ambiguity.

ACKNOWLEDGEMENTS

The authors here sincerely acknowledge the financial and technological support obtained from Prof. Dr. A. S. Chaudhury, Honb’le Director of Camellia School of Engineering and Technology and thank him for his constant motivation in bringing up this crucial research work.

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BIOGRAPHIES

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LIST OF FIGURES

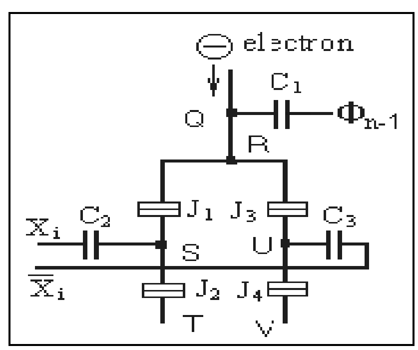

Fig -1: Basic tunneling phenomena in an SET

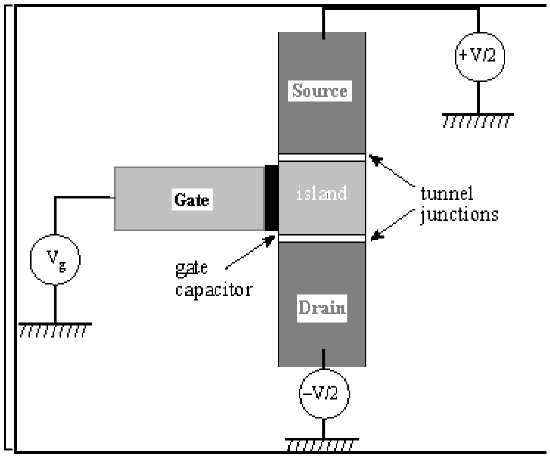

Fig -2: Schematic of SET structure

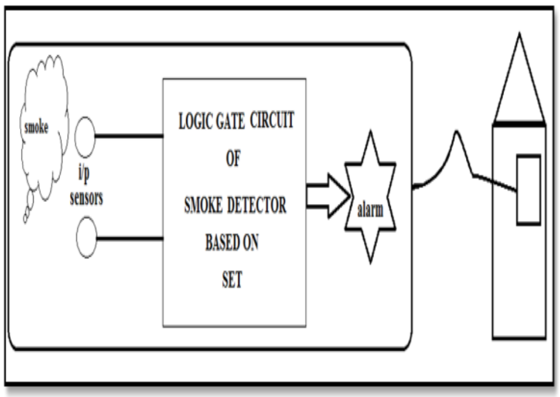

Fig -3: A pictorial setup of Smoke Detector Alarm along with its logical block diagram

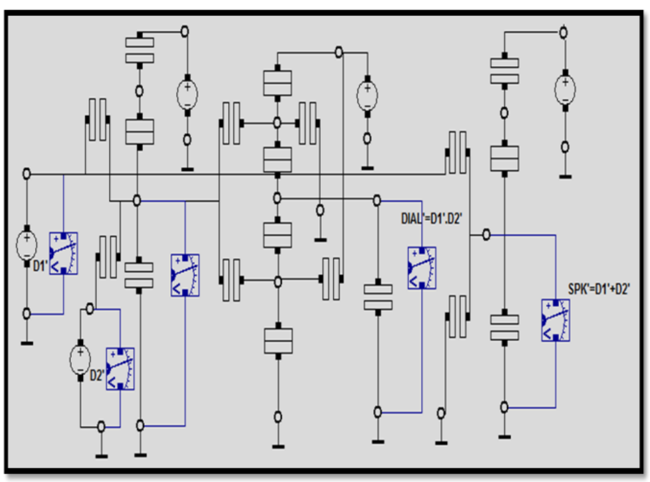

Fig -4: SET based Logic circuit of Smoke Detector with inputs denoted as D1` & D2`; output as DIAL`=D1`.D2` and SPK`=D1`+D2`