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Implementation of an amorphous silicon carbide, ultra-high-speed switch for improving FPGA's interconnect switching

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Abstract: A novel solution for improving FPGA's operation is proposed here, for the first time. The use of a crystalline silicon based switch, which incorporates in fabrication procedure a 0.1 microns thin film of amorphous silicon carbide, is presented in this paper. The above switch exhibits a rise time value of about 10ps, which is the lowest ever reported and compared with switching time of 50-300ns of MOSFETs used in FPGAs interconnect switching, can lead to very fast FPGA's operation. The switch can be triggered from OFF to ON state by using a gate electrode. It can also be triggered by incident light, thus making it capable for future FPGAs photonic application.

Keywords: FPGAs, interconnect switches, amorphous silicon carbide ultra-high-speed switch.

I. INTRODUCTION

FPGAs have the main advantage of combining software and hardware, thus having the ability of hardware programming for a series of applications. There are several applications using an FPGA, such as digital signal processing, biomedical instrumentation, device controllers, software-defined radio, random logic, medical imaging, computer hardware emulation, voice recognition, cryptography, filtering and communication encoding, and more.

Consumer electronics applications include smartphones, autonomous vehicles, cameras, displays, video and image processing, and security systems. Many commercial applications also make use of the FPGA advantages, like in servers, and various markets, including aerospace and defense, medical electronics, and distributed monetary systems.

All the above make obvious the need for faster and more efficient FPGAs. Several efforts towards this direction are reported. Programmability to reduce FPGA interconnect power[(1)], or use of low-power FPGA routing switches using adaptive body biasing technique[(2)], as well as high performance programmable interconnect resource design investigations[(3)].

Other works present the design of FPGA's high-speed and low-power programmable interconnect[(4)], or an automatic transistor-level tool for GRM FPGA interconnect circuits optimization[(5)], while another work shows a via-switch FPGA with transistor-free programmability enabling energy-efficient near-memory parallel computation[(6)].

None of the above research efforts reported about a significant increase in FPGA's switching speed, which exhibits great dependence on internal FPGA's MOSFET transistor switching time values. This paper presents for the first time, a three orders of magnitude increase of interconnect switching speed from nanoseconds to picoseconds, leading to much faster FPGA operation, by using an amorphous silicon carbide switch.

II. A BRIEF PRESENTATION OF FPGA'S INTERNAL STRUCTURE AND THE NEED FOR ITS FASTER SWITCHING

Figure1 presents internal structure components of an FPGA. Main parts appear are Configurable Logic Blocks (CLBs), Programmable Interconnects and I/O Blocks. FPGAs internally utilize configurable logic blocks (CLBs), programmable interconnects, and I/O blocks to implement digital circuits.

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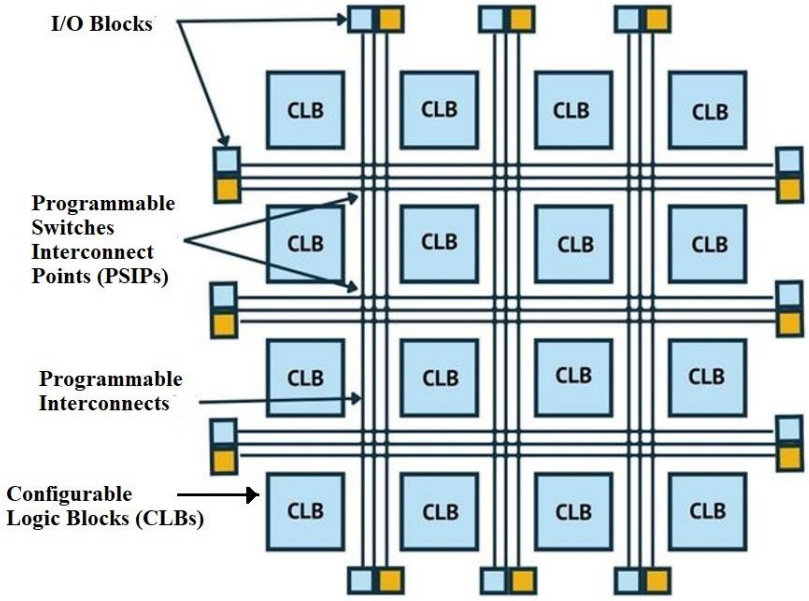

Figure 1: Internal structure components of an FPGA

Configurable Logic Blocks (CLBs) are the fundamental building blocks of an FPGA, containing logic gates and a small amount of memory. They are programmed to perform specific logic functions and are interconnected to form complex circuits.

Programmable Interconnects are a network of wires that can be configured to connect CLBs, allowing for routing of signals between different blocks. This programmable routing infrastructure allows users to customize the FPGA for specific applications.

I/O (Input/Output) Blocks provide a connection between the internal logic of the FPGA and the external world, allowing the device to communicate with other components.

Figure2 shows programmable switches interconnect point block, with transistor switches playing critical role in FPGA's operation, since they control forming of specific circuits for corresponding applications.

It is clear from both Figure2 and Figure3 that horizontal and vertical interconnect wires are connected via transistor switch.

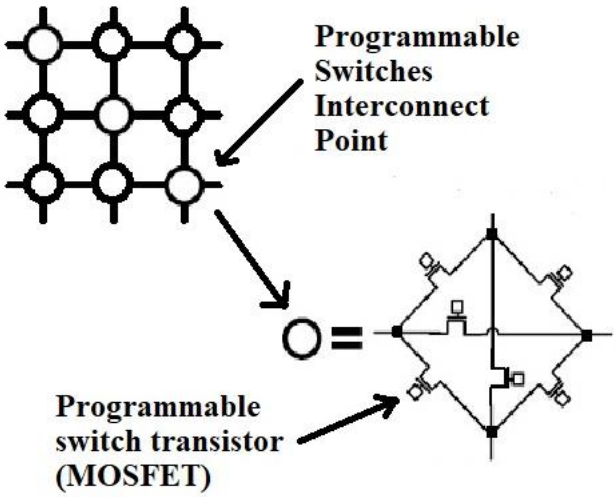

Figure 2: Programmable switches interconnect point block with transistor switches

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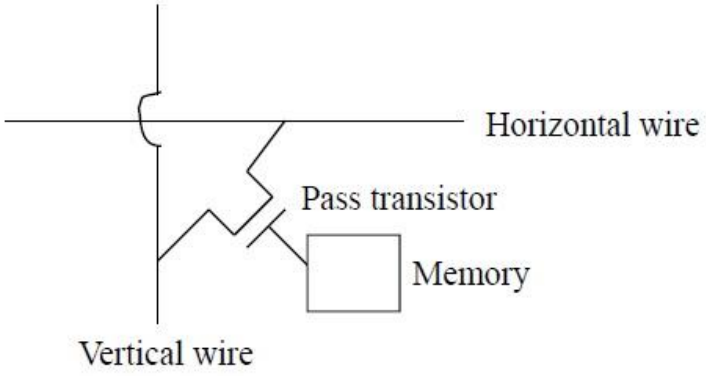

Figure 3: Horizontal and vertical wires are connected via transistor switch (Haibo Wang, Southern Illinois University)

All the above indicate the definitive role of transistor switches for FPGA's fast operation. MOSFETs are the transistor switches used in FPGAs and Figure4 presents a classic N-channel MOSFET connected as a switch. The operation of this MOSFET is simple. VGS is gate to source voltage and VThreshold is the critical voltage value to turn ON the MOSFET switch. Operations modes are shown below.

N-channel MOSFET operating modes for switching:

Condition	Operation
VGS < VThreshold	Open switch (OFF)
VGS > VThreshold	Short circuit (ON)

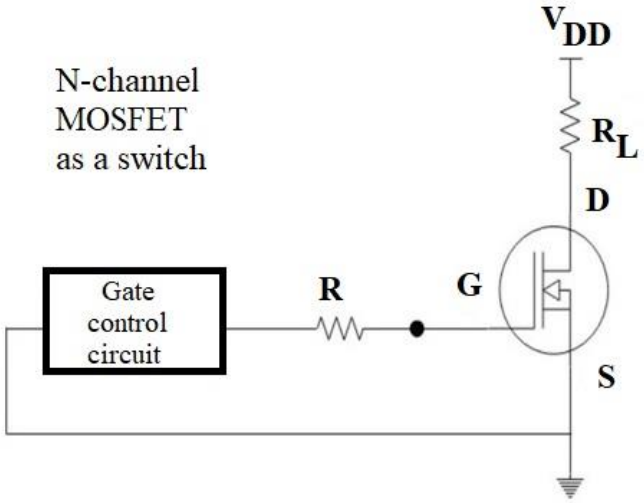

Figure 4: N-channel MOSFET as a switch

It is obvious that the transistor switching, meaning how fast a transistor can switch ON/OFF, plays definitive role on FPGA's operation speed. MOSFETs' switching times can range from 50ns to 300ns depending on the device and application.

III. IMPLEMENTATION OF THE AMORPHOUS SILICON CARBIDE (A-SIC) SWITCH, IN THE FPGA STRUCTURE

Figure 5 presents a cross-sectional view of the proposed improved switch.

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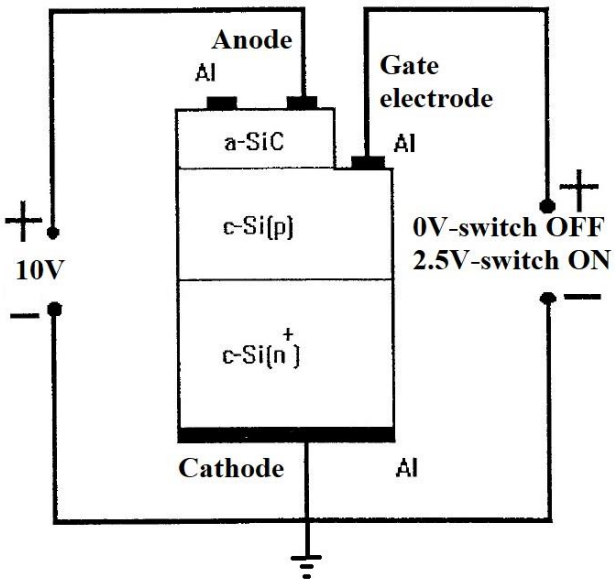
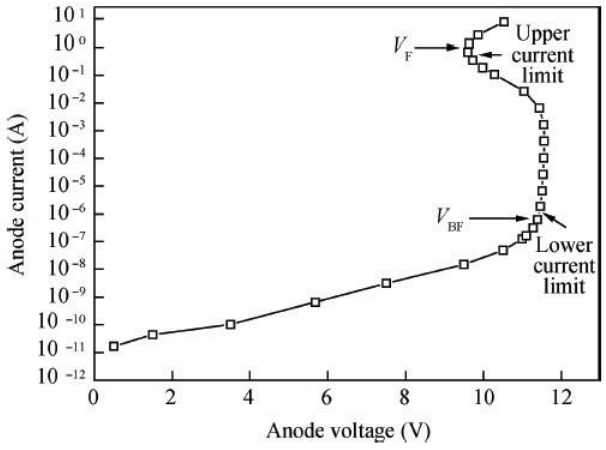


Figure 5: Cross-sectional view of the proposed improved switch

We presented elsewhere the fabrication, characteristics and modeling of the initial switch[7] and its high-speed behavior[8]. The switch consists of the semiconductor layers shown in Figure5 which are Aluminium(Al)/amorphous silicon carbide(a-SiC)/crystalline silicon-p(c-Si(p))/crystalline silicon-n^+(c-Si(n^+))/Aluminium(Al). Then a successful simulation was performed[9] for the switch, using Silvaco software and the final result was an improved device, which exhibited the lowest ever reported rise time of 10ps, for this kind of switches[10].

Figure 6 shows simulated I-V characteristics of the proposed improved switch with fabrication characteristics also shown. We observe that the switch goes to ON state for an anode to cathode voltage of 11Volts which is called forward breakover voltage V_{BF}. At the ON state the switch maintains a stable voltage drop across it, which is called forward voltage drop V_F and has a value of 9.5Volts. It is worth to mention that, as shown in Figure 6, at the OFF state of the switch we observe current values less than 10^{-8} A, meaning that the switch exhibits very good blocking behavior, which is great advantage for FPGAs or other application.



Simulated I–V characteristics of the improved Al/a-SiC/c-Si(p)/c-Si(n^+)/Al switches (a-SiC film width = 0.1 μm, c-Si(p) doping concentration = 3×10^{17} cm^{-3}, c-Si(p) region width = 15 μm, c-Si(n^+) doping concentration = 8×10^{19} cm^{-3}, c-Si(n^+) region width = 20 μm, active device area = 0.785 mm^2).

Figures 6: Simulated I-V characteristics of the proposed improved switch (fabrication characteristics also shown) Reference 10

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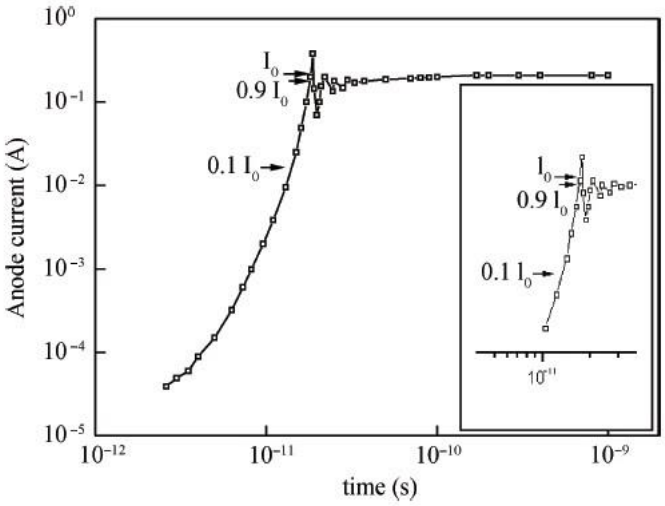
Figure 7 presents simulated rise time characteristics of the proposed improved switch.



Simulated characteristics of anode current versus time (rise time characteristics) of the improved Al/a-SiC/c-Si(p)/c-Si(n^+)/Al switches

Figure 7: Simulated rise time characteristics of the proposed improved switch. Reference 10

It is clear from the above Figure 7 that the improved switch exhibits a rise time value of $1X10^{-11}s = 10X10^{-12}s = 10ps$, being the lowest ever reported value.

We mentioned above that an FPGA consists of several internal hardware blocks with user-programmable interconnects in order to customize operation for a specific application. These interconnects can be reprogrammed, allowing the FPGA to accommodate changes to the design or support a new application.

Taking into account the above statement we can understand the reason of urgent need for fast switching in FPGA's user-programmable interconnects and that constitutes the main objective of this paper, which is the use of amorphous silicon carbide switch instead of MOSFET transistor switch.

It must be mentioned that the proposed a-SiC switch of Figure 5 resembles MOSFET of Figure 4 with anode, cathode and gate electrodes corresponding to drain, source and gate, respectively. This gives a manufacturing advantage since no significant changes must be done for the replacement of MOSFET with a-SiC switch, the main of them being amorphous silicon carbide thin film (0.1 microns, nano-film) deposition.

Another important note is that our switch can be triggered by a small voltage in order to transit from OFF to ON state. When a positive potential is applied to gate electrode V_{BF} voltage value decreases and the switching occurs at lower voltage values. Below we present Table1 showing positive potential values at gate electrode and their corresponding V_{BF} reduction values.

Table 1

Positive potential at gate electrode (V)	Reduction of V_{BF} values (V)
1.5	0.68
2.0	0.91
2.5	1.14
3.0	1.37
5.0	2.28

Taking into account that our proposed switch has V_{BF} value of 11V we can apply an anode-cathode voltage of 10V and trigger the switch to ON state, according to Table1, with a positive gate potential of 2.5V, because V_{BF} value will be reduced then to
11V-1.14V= 9.86V.

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Another important advantage of our switch is that it can also be triggered by incident light, giving it the advantage of application to possible future photonic FPGA or other devices.

Finally the V_F (forward voltage drop across the switch at the ON state) value of 9.5V can easily be divided by resistor voltage divider, in order to be reduced at 5V or other specific voltage value, according to manufacturer needs.

IV. CONCLUSION

FPGA's interconnect switching speed improvement is a critical parameter for obtaining faster devices. A novel method for achieving this goal, is presented in this paper. The use of an ultra-high-speed switch, based on silicon technology and using a thin film of 0.1 microns amorphous silicon carbide, is implemented in order to increase FPGA's switching operation. The above switch exhibits rise time value of 10ps, which is extremely low compared with corresponding values of 50-300ns obtained by MOSFETs. The proposed a-SiC switch can be voltage triggered as well as light triggered, in order to succeed the OFF state to ON state transition, thus making it suitable to replace MOSFET transistors in FPGAs interconnect switching part.

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