Application of SWSFET in Image Segmentation

Supriya Karmakar (mr.supriyakarmakar@gmail.com)
Farmingdale State College

Research Article

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Abstract

Image segmentation is a fundamental image processing technique to extract the required information from an image. The core element of any integrated circuit (IC) chip for signal processing is the metal oxide semiconductor field effect transistor (MOSFET). There are various limitations of MOSFET in sub-nm process technology. This work introduces the application of a new type of MOSFET, which is known as the spatial wave function switched field effect transistor (SWSFET), in the image processing application. The channel in a SWSFET is comprised of various low bandgap semiconductor layers. The charge carriers move across various channels and generate current through different drain terminals. The SWSFET is used to design a window detector which is applied in image segmentation.

1. Introduction

Image segmentation is a fundamental image processing technique. In the image segmentation an image is segmented into different contours or sone for information extraction. The level of segmentation depends on the image and the information needs to acquire from it. In the image segmentation the pixels of an image are assigned various label based on the characteristic's parameter for the segmentation. Same label for different pixels means same characteristics for those pixels. As a result, the image is segmented into different contours where inner-contour pixels has some common characteristics. [1-3].

Most popular implementation of image segmentation is based on CMOS logic circuits. The device dimensions in the CMOS logic are always shrinking to support various objectives such as device integration, increase speed and decrease power etc. But in the sub-nm range, the structural limits of the device affects the fundamental operation of the device and affects the device characteristics. The conventional CMOS devices may not be able to support the future demand for data processing and signal processing. So new semiconductor devices are in research phase to support semiconductor era in sub-nm range.

A spatial wavefunction switched field effect transistor (SWSFET) is a conventional FET having low bandgap channels between the source and the drain region [4-6]. The characteristics of SWSFET makes it applicable for various circuit operation for multivalued logic (MVL) implementation. The dimensions of an isolated SWSFET doesn't increase significantly compared to a MOSFET because the multiple low bandgap channels are included inside the body of the SWSFET structure. Besides this SWSFET can produce more than two states unlike conventional MOSFET and reduce circuit element in the complex circuit design.

2. Device Structure

The device structure of a SWSFET is shown in Fig. 1. The source and drain region is connected with a multiple quantum well (MQW) structure. The stack of low and high bandgap materials forms the MQW structure. In this device, two channels between the source and drain region are separated by high bandgap insulator materials. The source drain regions are connected to various channels and they are separated from other channels by insulators. In some circuit design, the drain terminals also needs to connect together. The drain terminals can be connected externally or internally. The gate contact is formed on top of the gate insulator like conventional FET.

3. Theory Of Operation

The gate voltage controls the charge movement along different quantum wells from the inversion layer between the source and drain region. Initially, the charge carriers tunnel from the inversion layer to the lower channel (further form the gate-insulator interface), and produce the drain current along this channel. Increased gate voltage helps charge carriers to switch to upper channels. This switching of charge carriers gradually decreases the drain current through lower channel and increase the drain current through upper channels. The drain terminals are fabricated using different drain contact holes to reach the corresponding channels and separate them with insulator.

The charge transfer and device operation can be explained by the self-consistent solution of the Schrödinger and the Poisson Equations. The movement of charge carriers depends on various parameters such as thickness of the well and the barrier, the relative energy bands in different wells etc. The device simulation results is shown in Fig. 2. The voltage at the gate terminal moves the electron concentration from the bottom channel to the top channel. The movement of charge carriers between different channels also shifts the current flow through different channels.

4. Circuit Model

The circuit model of the SWSFET is developed in VHDL. The conventional MOSFET circuit model, the threshold voltage is modified according to the Eq^n. 1. The circuit simulation is performed using NI Multisim. The image processing is performed using MATLAB R2020a. MCFET circuit model can be developed by modifying the threshold voltage of the conventional FET [$Eq.^n$ (1)]. The CV characteristics of the model data and MOS structure of two channel MCFET is shown in Fig. 3. Circuit model parameters are shown in Table 1.

$$
\begin{aligned}
&V_{\mathrm{THa}} = V_{\mathrm{THa}} && V_{\mathrm{GSEff}} < V_{\mathrm{TWell}} && \text{(a)}\\
&V_{\mathrm{THa}} = V_{\mathrm{THa}} + \alpha\left(V_{\mathrm{GSEff}} - V_{\mathrm{TWell}}\right) && V_{\mathrm{GSEff}} > V_{\mathrm{TWell}} && \text{(b)}\\
&V_{\mathrm{THb}} = V_{\mathrm{THb}} && && \text{(c)}\\
&\alpha = \frac{\left(V_{\mathrm{GSEff}} - V_{\mathrm{TWell}}\right)}{\left(V_{\mathrm{THb}} - V_{\mathrm{TWell}}\right)} && && \text{(d)} \qquad (1)\\
&V_{\mathrm{Poly}} = \frac{\left[q\varepsilon_s n_{\mathrm{gate}} C_{\mathrm{OX}}^2\right]10^6}{2}\left[\sqrt{1+\frac{2\left(V_{\mathrm{GS}} - V_{\mathrm{FB}} - 2\phi_{\mathrm{f}}\right)}{\left[q\varepsilon_s n_{\mathrm{gate}} C_{\mathrm{OX}}^2\right]10^6}} - 1\right]^2 && && \text{(e)}\\
&V_{\mathrm{PolyEff}} = 1.12 - 0.5\left(1.12 - V_{\mathrm{Poly}} - \delta + \sqrt{\left(1.12 - V_{\mathrm{Poly}} - \delta\right)^2 + 4.\delta.(1.12)}\right) && && \text{(f)}\\
&V_{\mathrm{GSEff}} = V_{\mathrm{GS}} - V_{\mathrm{PolyEff}} && && \text{(g)}
\end{aligned}
$$

where n_{gate} : Doping concentrations in the Poly-Si gate

V_{TWell}: Transition voltage between two channels

V_{THa}: Lower channel threshold voltage

V_{THb}: Upper channel threshold voltage

α : Matching parameter

V_{GS} : Gate-to-Source voltage

V_{GSEff}: Effective gate-to-source voltage

V_{PolyEff}: Voltage drop in the Poly Si gate

C_{OX}: Gate capacitance

V_{FB}: Flat band voltage

Φ_{f} : Surface potential

Q: Electron charge

δ = 0.01

ϵ_{s} : Permittivity

Table 1: Parameters for device model simulation

Parameter	Value
Length	5.0 µm
Width	10 µm
V_{THa}	0.7 V
V_{THb}	1.1 V
V_{TWell}	0.9 V
V_{DD}	3.0 V
	1.0

5. Membership Function

The membership function determines the presence or absence of an input within a range or a group. The function generates two different states depending on the input member. The membership function can be represented according to Eqn. (2).

$$y = \begin{cases} 0 & 0 < x < x_L \\ 1 & x_L < x < x_H \\ 0 & x > x_H \end{cases} \qquad (2)$$

The output (y) has two different states based on the value of x. The output is high, when thw input (x) is in between xL and xH. The output is low, when the input is not in between xL and x_H.

The circuit diagram of membership function using two channel SWSFET is shown in Fig. 4. Two sources and two drains are of the SWSFET are isolated in this architecture. Two source voltages determine the lower limit and upper limit of the range of the membership function. The input function is applied in the gate region of the SWSFET. The drain current will flow in different drains based on the applied gate voltage. When the applied gate-source(VGS) voltage is more than the threshold voltage of the channel, the drain current will flow through

that channel and output voltage will drop across the load resistances(RLs). Comparator after load resistance (RL) are used to convert the output voltages to Rail-to-Rail transition. The following XOR gate will produce either low(0) or high(1)voltage based on the relation

between the output of two comparators. The output of membership function is shown in Fig. 5.

6. Experimental Results

An image can be segmented based on any parameter associated with the image. Among various parameters, the gray level of an image is a very fundamental parameter to be used for the image segmentation. Image segmentation can be

performed in different methods. Thresholding techniques is very important because of fast processing, manipulation and less storage space. In thresholding, different regions of the image are segmented based on the different intensity levels within the image.

Generally thresholding can be two level (bi-level) or multilevel. The two level thresholding is used when to convert an image into binary logic. In binary logic there are only two levels and teo level thresholding is useful for that[8]. Multilevel thresholding is used for segmentation

of color image into multiple levels [9]. Generally, background corresponds to one level and other gray levels correspond to various levels. Depending on the application, different thresholding methods are chosen. The segmented image in multilevel thresholding can be

expressed as Eq^{n}.(3), where Tk, ($k = 1, 2, 3\ldots J-1$) are the threshold values with ($T1<T2<T3<\ldots\ldots<TJ-1$),

$$I_T(x,y) = \begin{cases} m_0 & I(x,y) \le T_1 \\ m_1 & T_1 < I(x,y) \le T_2 \\ . & \\ . & \\ m_{J-1} & I(x,y) > T_{J-1} \end{cases} \quad (3)$$

where m_k represents the mean histogram values in the range (T_k, T_{k+1}) with $T_0 = 0$ and $T_J = 255$).

In this paper, different window for multilevel threshold are designed by SWSFET based membership function circuit by varying the window position throughout the full scale of the intensity. The flow diagram of the image segmentation using SWSFET based membership function is shown in Fig. 6. Image segmentation using SWSFET based window detector is demonstrated in Fig. 7 where original image is in Fig. 7(a). Figure 7(b) to Figure 7(d), shows the output of the segmented image where different number of window detectors are used to segment the original image. The number of window detector determined the number of segmentation levels. The number of segmentation levels increases from two to eight gradually from Fig. 7(b) to Fig. 7(d).

Another application of segmentation is shown in Fig. 8 where the background extraction is performed by using image segmentation.

The SWSFET based image segmentation is evaluated using four evaluation methodologies. These four methodologies are global consistency error (GCE) [7], variation of information (VI) [8], boundary displace error (BDE) [8], probability random index (PRI) [9]. The comparisons are made with another four algorithms. They are mean shift (MS) [10], efficient graph-based algorithm (EGB) [10] and two other algorithm proposed in An et. al. [11]. The comparison in Table 2 shows that SWSFET based circuits are more accurate and efficient.

Another application of image segmentation is graph cut method which is used to extract object from its image. Window detector can also be used to extract object from its image which is performed using graph cut algorithm. There are different algorithms for graph cuts [12]. Using graph cut method, image background also can also be changes. Fig. 8 shows the application of graph cut method to change the background of the image.

Table 2: The average values of different methodologies

Algorithm	PRI	VI	GCE	BDE
MS [9]	0.7550	2.4770	0.259	9.7001
EGB [10]	0.7841	2.6647	0.2895	9.9497
CSW [11]	0.7231	2.7603	0.2341	8.7450
CSC [11]	0.7961	2.7320	0.2250	8.6349
Proposed work	0.7073	2.176	0.2109	8.0059

7. Conclusion

In this paper the multi-level image segmentation using spatial wave function switched field effect transistor (SWSFET) is presented. The SWSFET can be fabricated using conventional CMOS process. The SWSFET generally fabricated in InGaAs material systems. Because of their higher electron mobility SWSFET based circuits are faster than others. SWSFET based window detector is successfully used to implement image segmentation in this paper. Graph cut algorithm is also implemented to change image-background using SWSFET.

Declarations

*Funding statement

No funds, grants, or other support was received.

*Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

*Author contributions

The author is the only contributor in this work

***Availability of data and material**

They are available upon request.

***Compliance with ethical standards**

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***Consent to participate**

'Not applicable

***Consent for Publication**

'Not applicable

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'Not applicable

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Figures

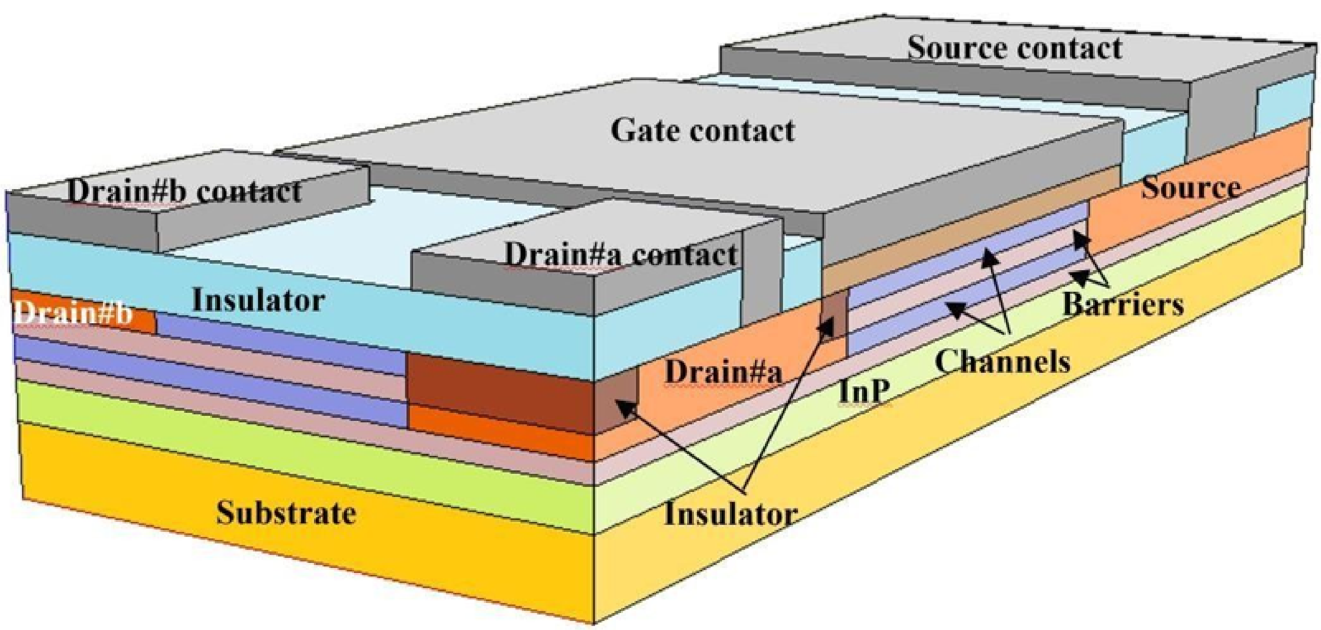

Figure 1

Two wells (channels) SWSFET

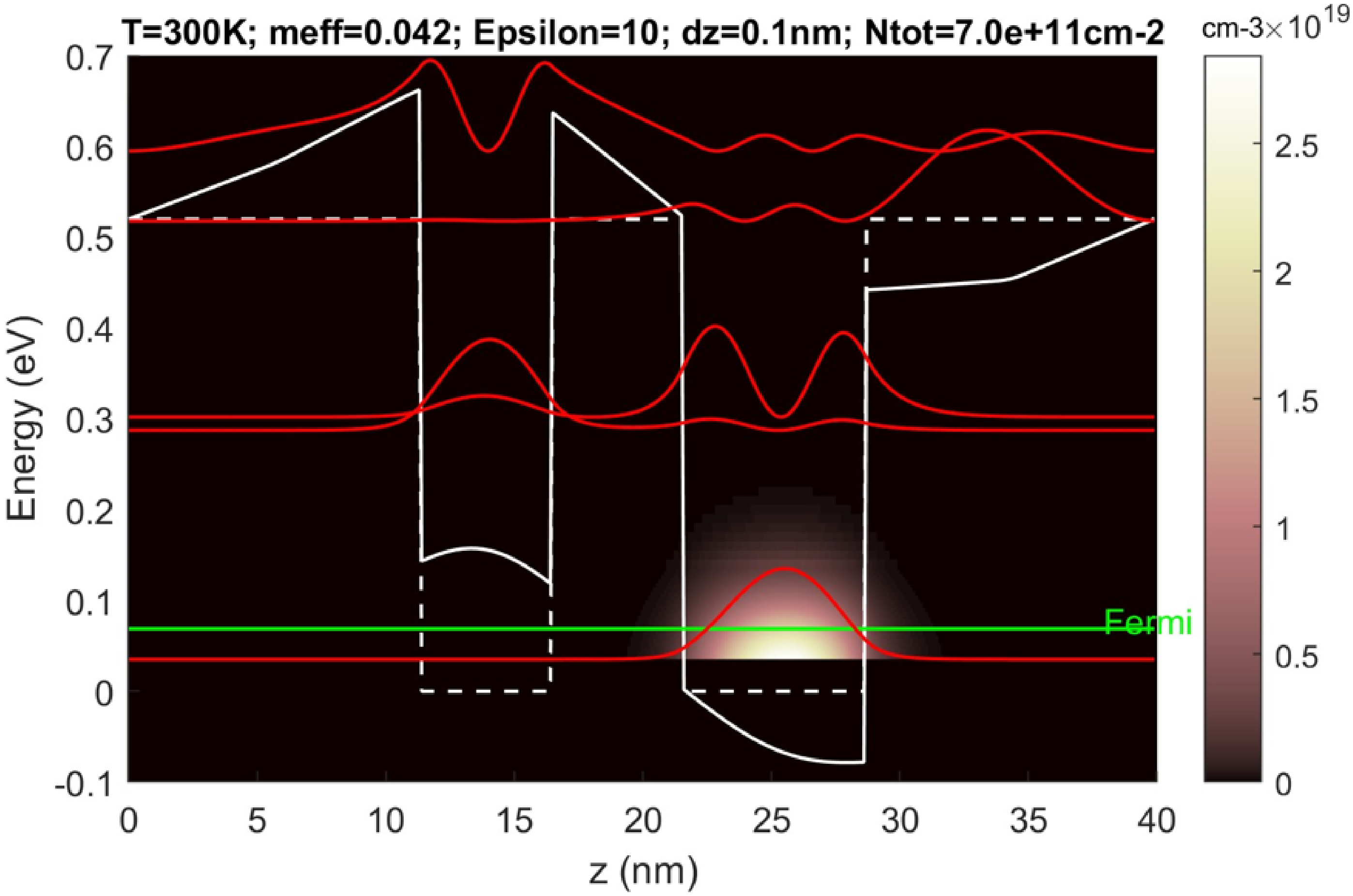

Figure 2

Electron wavefunction localization in different channels of a two channel SWSFET

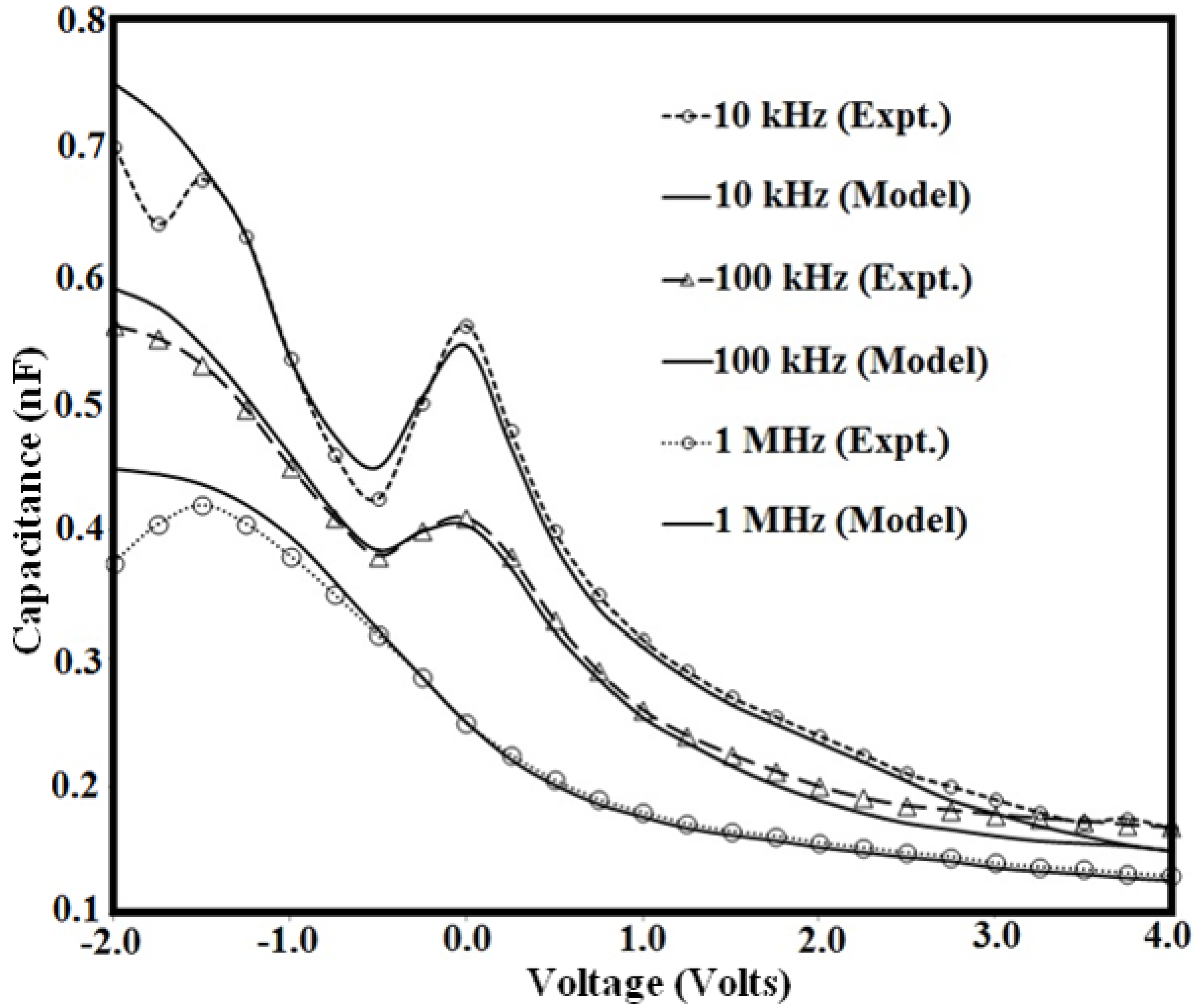

Figure 3

Comparison of experimental C-V characteristics and model data of two channel SWSFET [8]

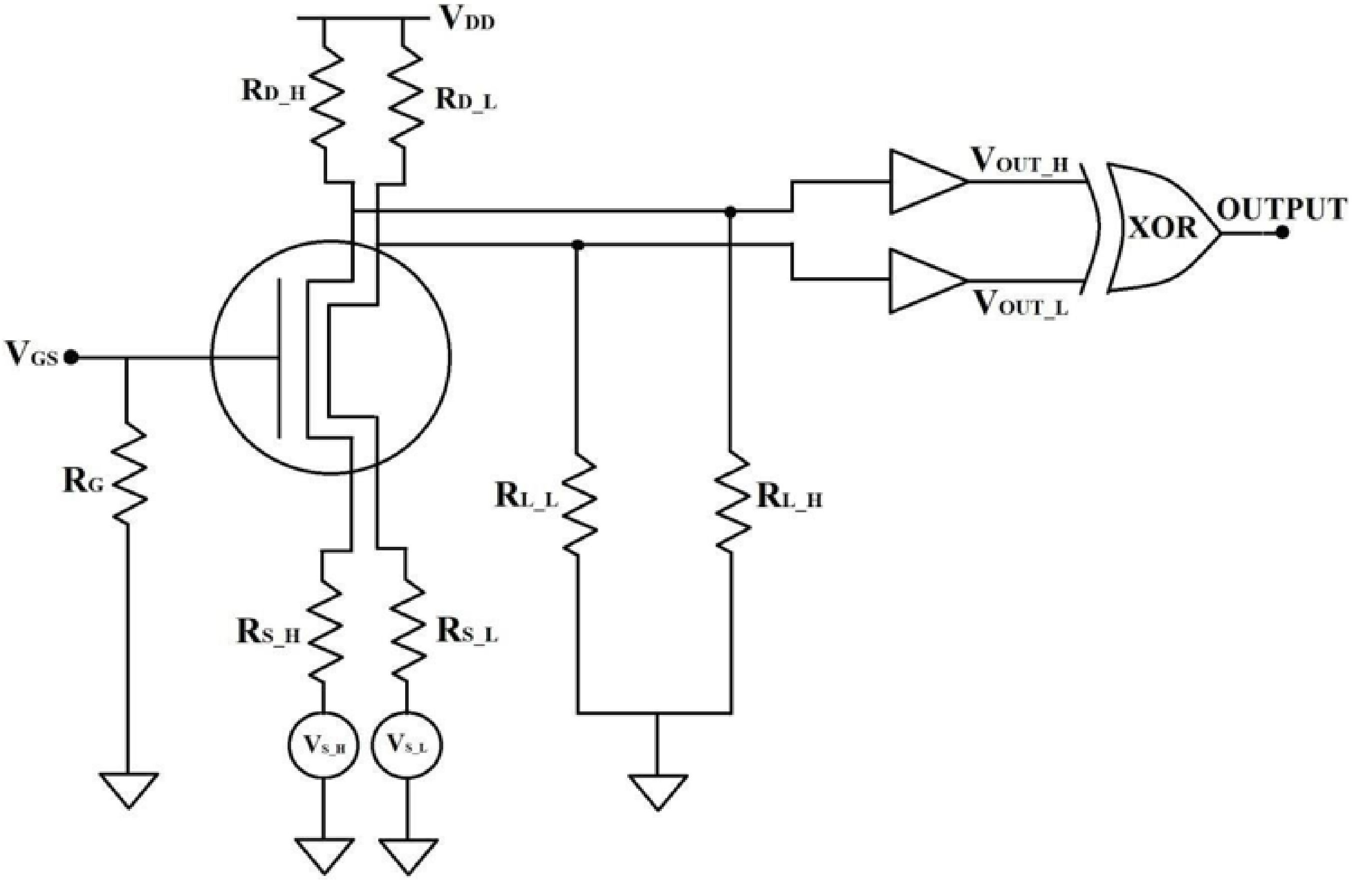

Figure 4

Circuit diagram of window detector with SWSFET

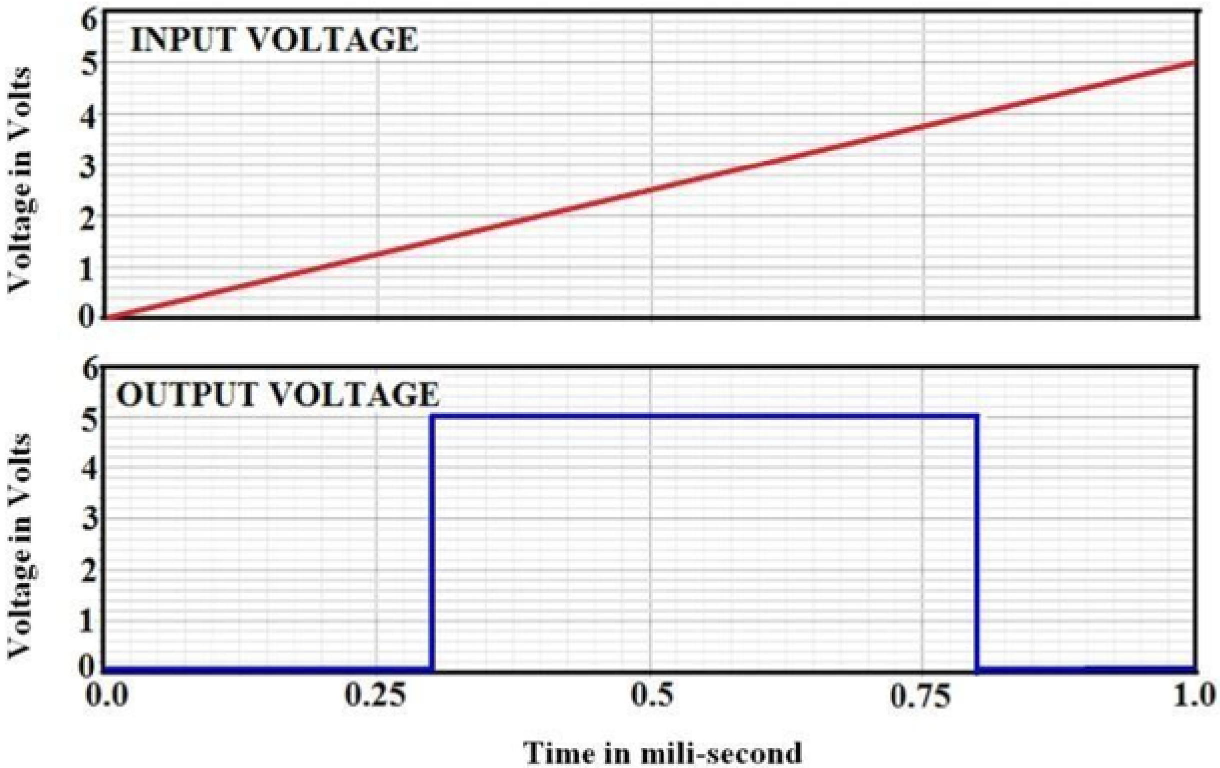

Figure 5

Input-Output waveform of window detector

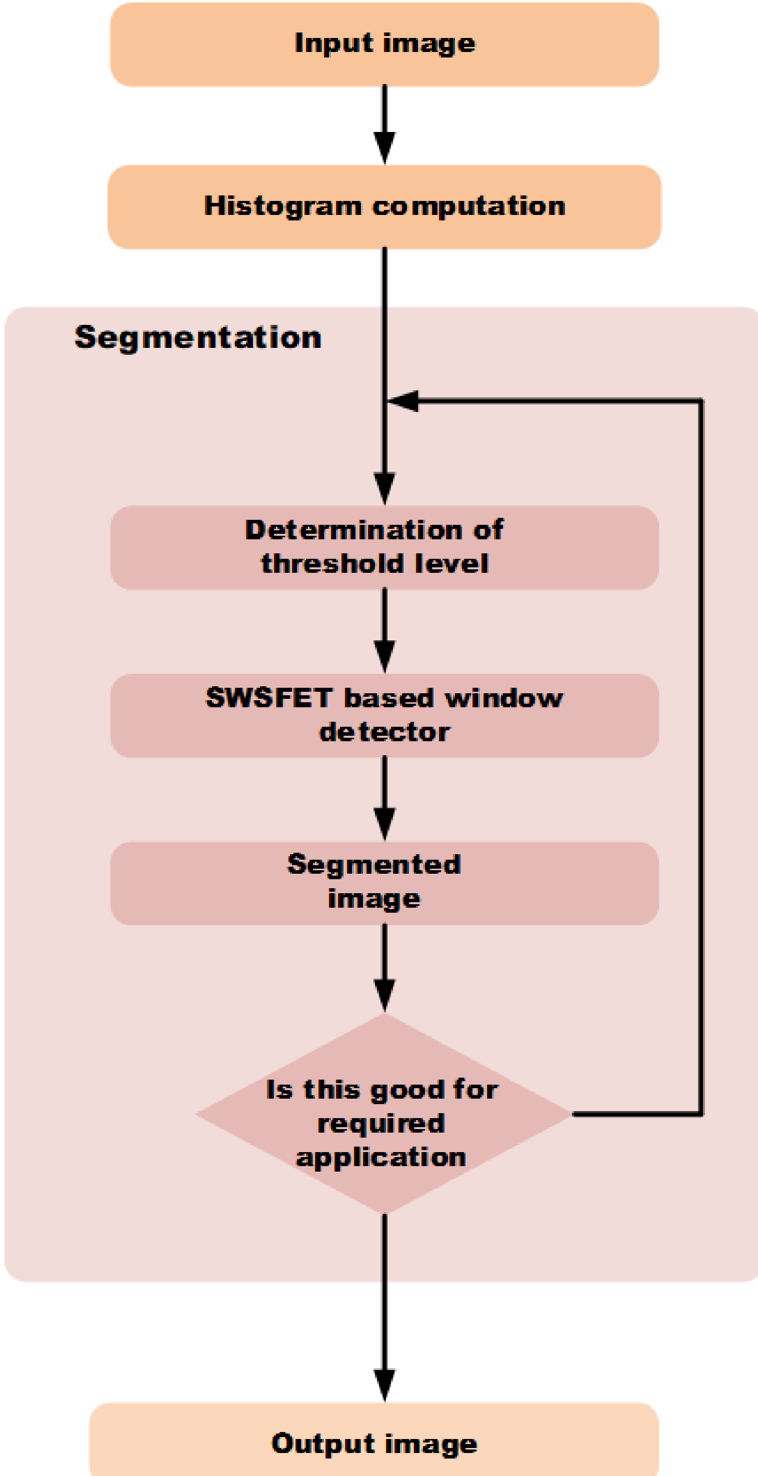

Figure 6

Flow diagram of segmentation based on threshold level

Figure 7

Color image segmentation: a Original color image b-d segmented image where different number of window detectors (membership function circuits) are used from b-d.

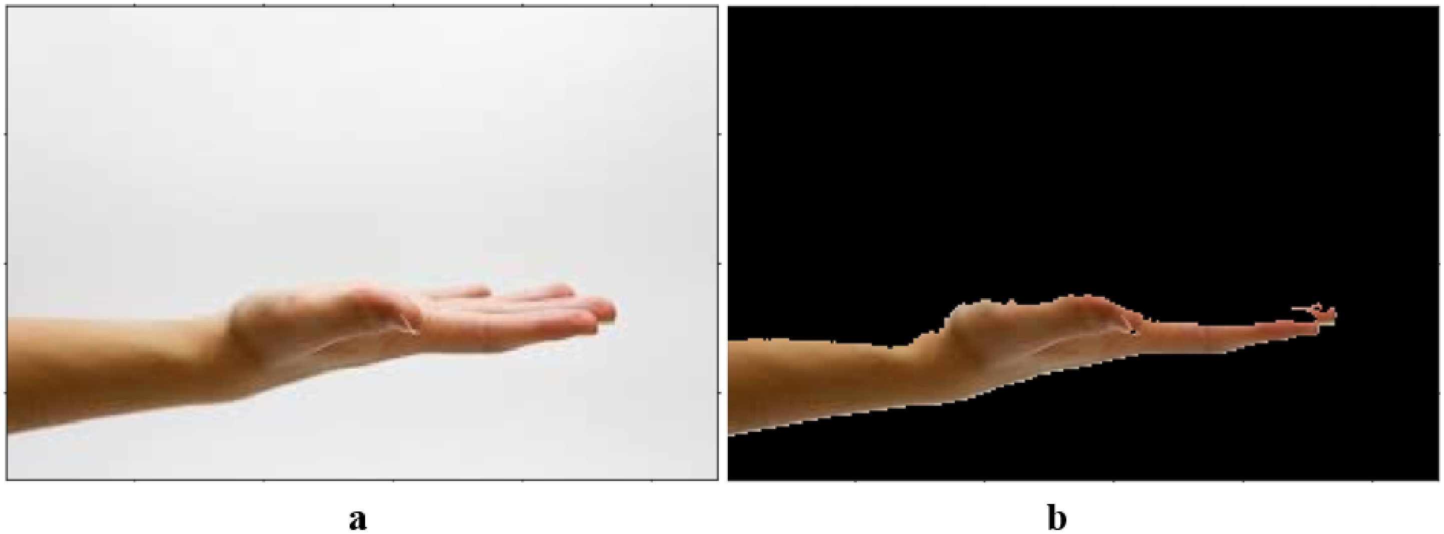

Figure 8

a Original image b Removal of back ground