HOT CARRIER STUDIES ON HETEROSTRUCTURE SILICON GERMANIUM P-CHANNEL METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Faculty : Engineering

This study examines the susceptibility of hot carrier effects on various Heterostructures Silicon Germanium P-Channel Metal Oxide Semiconductor Field Effect Transistor (SiGe PMOSFET) such as Strained SiGe Channel and Strained SiGe Source/Drain PMOSFET. The results were compared with Si Channel PMOSFET.

The hot carrier effect of these structures was investigated in the aspect of material, structural and mobility via impact ionization. Simulations were performed with ATLAS/BLAZE 2D to design the device structures and to simulate the hot carrier effects indicated by substrate and gate current.

The SiGe heterostructure PMOSFETs have higher hot carrier effects as verified by substrate current with an increase of 131% for Strained SiGe Channel PMOSFET and 199% for Strained SiGe Source and Drain PMOSFET with 25% Ge fraction respectively as compare to the Si PMOSFET. The increase of hot carrier effects in SiGe structure is due to higher impact ionization rate approximately an order of magnitude in SiGe as compared to Si.

The incorporation of Si-cap in the SiGe heterostructure enhanced the suppression of hot carrier injected into the gate. However the buried layer of Strained SiGe channel PMOSFET suppresses the impact ionization rate to a certain level of thickness. Beyond that impact ionization increases with the Ge content as verified by substrate current. On the other hand the increase of Ge content suppressed further the hot carrier injection into the gate due to higher valence band energy between the SiGe channel and the Si-cap.

As a thicker layer of p+SiGe in the drain region is fabricated in the Strained SiGe Source and Drain PMOSFET result shows an enhancement in the hot carrier effect. This is caused by a higher impact ionization rate in SiGe and also most area of impact ionization is covered as the thickness of SiGe layer is increased.

In the aspect of mobility, the high mobility SiGe channel PMOSFET enhanced further the hot carrier effects through the enhancement of current drive whereas hot

carrier effects decreases in the Strained SiGe Source and Drain PMOSFET despite setting a higher low field mobility in the p+ SiGe source and drain region. In fact the current drive in Strained SiGe Source and Drain PMOSFET is lower than Si Channel PMOSFET due to the valence band discontinuity that causes a higher barrier height for holes flowing from source to drain. This indicated that the hot carrier is also affected by current drive.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KAJIAN KESAN PEMBAWA PANAS DALAM TRANSISTOR OXIDA LOGAM KESAN MEDAN, STRUKTUR-HETERO SILICON GERMANIUM SALURAN P

Oleh

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November 2004

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Fakulti : Kejuruteraan

Kajian kesan pembawa panas telah dibuat ke atas beberapa Transistor Oxida Logam Kesan Medan, Struktur-Hetero Silicon Germanium Saluran P (SiGe PMOSFET) seperti Terikan Saluran SiGe PMOSFET dan Terikan Punca dan Salir SiGe PMOSFET. Keputusannya dibandingkan dengan saluran Si PMOSFET.

Kesan pembawa panas dikaji dari aspek struktur bahan, struktur dan kelincahan via pengionan hentaman dan pembawa panas dapat dibuktikan oleh arus substrat dan arus get. Penyelakuan dibuat dengan menggunakan ATLA/BLAZE 2D.

Heterostruktur PMOSFET menunjukkan peningkatan kesan pembawa panas Kesan ini telah dibuktikan oleh arus substrat yang menunjukkan penigkatan sebanyak 131% dalam struktur Terikan Saluran SiGe PMOSFET dan 199% dalam struktur Terikan

Punca dan Salir SiGe PMOSFET dengan peratusan Ge sebanayk 25% masing masing berbanding dengan Si PMOSFET. Punca peningkatan kesan pembawas panas adalah disebabkan oleh pengionan hentaman yang lebih tinggi sebanyak 10 kali dalam SiGe berbanding dengan Si.

Tetapi pengionan hentaman dapat dikurangkan apabila tukup-Si diendapkan ke atas kedua-dua heterostruktur SiGe PMOSFET. Namun pengurangan perngionan hentaman disebabkan lapisan terpendam SiGe mempunyai hadnya. Pengionan hentaman akan meningkat dengan penambahan Ge apabila had ini telah dibatasi. Kesan ini telah dibuktikan oleh arus substrat.

Untuk kesan pembawa panas yang melonjat ke atas gate, didapati pengionan hentaman berkurangan apabila peratusan Ge ditingkatkan. Hal sedemikian adalah disebabkan oleh tenaga jalur valensi yang lebih tinggi di antara lapisan terpendam SiGe dan tukup-Si yang dapat mengurangkan suntikan pembawa panas ke atas get.

Dalam struktur Terikan Punca dan Salir SiGe PMOSFET kesan pembawa panas meningkat apabila p+SiGe yang tebal dalam kawasan drain difabrikasikan. Dengan adanya p+SiGe yang lebih tebal, lebih banyak kawasan pengionan hentaman dapat diliputi seterusnya meningkatkan kesan pembawa panas.

Dari aspek kelincahan pula Terikan Saluran SiGe PMOSFET menunjukkan peningkatan dalam kesan pembawa panas apabila kebolehgerakan dinaikkan. Hal ini adalah berbeza dengan struktur Terikan Punca dan Salir SiGe PMOSFET. Walaupun kelincahan telah ditingkatkan dalam kawasan p+SiGe didapati kesan pembawa panas tidak meningkat sebaliknya berkurangan. Di samping itu didapti bahawa arus salir dalam struktur ini adalah kurang berbanding dengan Si PMOSFET disebabkan ketakselanjaran dalam jalur valensi yang mengingkatkan ketinggian sawar untuk arus lubang mengalir dari sumber ke salir. Ini menunjukkan bahawa arus salir merupakan faktor yang penting dalam kesan pembawa panas.

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I certify that an Examination Committee met on 9th November 2004 to conduct the final examination of Kenny Gan Chye Siong on his Master of Science thesis entitled "Hot Carrier Studies on Heterostructures Silicon Germanium P-Channel Metal Oxide Semiconductor Field Effect Transistor" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertaninan Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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KENNY GAN CHYE SIONG

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