QUANTUM MECHANICAL EFFECTS ON THE PERFORMANCE OF STRAINED SILICON METAL-OXIDE-SEMICONDUCTOR FIELD-EFFECT TRANSISTOR

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To my beloved family

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ABSTRACT

In recent development of nanoelectronic devices, strained silicon Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) has been identified as a promising structure for the future nanoscale device. Strained silicon is an attractive option due to the enhanced carrier mobility, high field velocity and carrier velocity overshoot. However, the aggressive geometry scaling has approached a limit where the classical mechanism is insufficient to clarify the characteristics of nanoscale MOSFET accurately. Beyond the classical limit, quantum-mechanical model becomes necessary to provide thorough assessment of the device performance. This research describes the modeling of nanoscale strained silicon MOSFET taking into account the critical quantum mechanical effects in terms of energy quantization and carrier charge distribution. Technology-Computer-Aided-Design (TCAD) simulations that apply the classical mechanisms are conducted to allow comparison with the developed models. It is shown that quantum mechanical effects become more dominant at channel length below 60nm. Significant discrepancy of threshold voltage as high as 90mV is found particularly in short channel regimes. The analytical model was also extended to the advanced structure of dual channel that provides higher electron and hole mobility compared to strained silicon MOSFET. The models were subsequently compared to the TCAD simulation results using a similar set of parameters as well as to the existing data from other literatures. Excellent agreements validate the models based on the physics of the quantum mechanical effects. In addition, the current-voltage model incorporating the quantum mechanical correction was also developed. The role of quantum capacitance over current drive in the channel was discussed. The developed models successfully replicate experimental data with proper physical explanation.

ABSTRAK

Pada era pembangunan peranti elektronik masa kini, penegang silikon semikonducktor oksida logam transistor kesan medan (MOSFET) telah dikenal pasti sebagai struktur semikonductor berukuran nano masa hadapan. Penegang silicon merupakan satu opsyen yang menarik disebabkan peningkatan dalam kebolehgerakan pengangkut, kelajuan medan tinggi dan kelajuan terlanjak. Tetapi, skala geometri yang agresif telah mencapai satu tahap dimana mekanisme klasikal tidak mencukupi untuk menerangkan tingkah laku MOSFET nano. Pada had melebihi fizik klasikal ini, model kuantum mekanik diperlukan bagi menyediakan satu penilaian penuh ke atas prestasi peranti. Kajian ini menerangkan model penegang silicon MOSFET nano yang menggabungkan kesan kritikal kuantum mekanik dari segi pengkuantuman tenaga dan taburan cas pengangkut. Teknologi-Reka Bentuk-Berpandukan-Komputer (TCAD) yang menggunakan mekanisme klasik dilakukan untuk membenarkan perbandingan dengan model-model yang dibangunkan. Ia menunjukkan bahawa kesan kuantum mekanik menjadi lebih dominan pada lebar saluran di bawah 60nm. Perbezaan ketara dalam voltan ambang setinggi 90mV ditemui terutamanya pada bahagian saluran pendek. Model analisis ini juga diperkembangkan untuk struktur dua saluran yang menyediakan kebolehgerakan yang lebih tinggi untuk elektron dan lubang berbanding dengan penegang silicon MOSFET. Model ini kemudiannya dibandingkan dengan TCAD dengan menggunakan satu set parameter yang serupa serta data yang sedia ada dari sumber literasi. Persamaan baik yang diperolehi mengesahkan teori fizik yang mengambil kira kesan kuantum mekanik. Tambahan pula, persamaan arus-voltan yang mengambil kira kesan kuantum mekanik turut diperolehi. Peranan kemuatan kuantum ke atas arus saluran turut dibincangkan. Model-model yang dibangunkan berjaya menepati data eksperimen dengan penerangan fizikal yang tepat.