Scaling Effect on Specific Contact Resistivity in Nano-scale Metal-Semiconductor Contacts

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INTRODUCTION

Progressive downscaling has allowed semiconductor industries to continuing improve the performance of integrated circuits (ICs) [1]. The downscaling adversely affects the performance of interconnects. Specifically, the resistivity of metal interconnects and metal-semiconductor contacts increases due to downscaling. The metal-semiconductor contact resistance, which acts as a parasitic source and drain contact resistance of a device is becoming a performance limiting factor as it takes larger fraction of the total on-state resistance [2]. Hence, the contact resistance must be reduced to meet ITRS performance requirements of future technology nodes.

As metal-semiconductor interface shrinks simultaneously as device shrinks, it becomes questionable if the resistivity still can meet the ITRS requirements when it reaches to the certain scaling limit (sub-10nm). Specific contact resistivity (ρ_C) is one of important factors affecting total contact resistance, and it is determined by important factors such as metal-semiconductor Schottky barrier height and semiconductor doping. This paper investigates the effects of contact geometry, Schottky barrier height, and doping concentration on the specific contact resistivity.

DEVICE DESCIPTION AND SIMULATION APPROACH

To gain substantial insight we chose simple 2-D and 3-D metal-semiconductor junctions (Fig. 1 (a)). The source region is a metal contact, and channel and drain regions are heavily n-doped Si contact pads (Fig. 1 (b)). The theoretical modeling of nanoscale structure demands a proper treatment of quantum effects such as the energy-level quantization caused by quantum confinement. Hence, a 2-D / 3-D quantum transport solver based on a self-consistent solution of the non-equilibrium Green's function (NEGF) and Poisson equations using the real-space effective mass approximation is used to simulate the metal-semiconductor devices. To investigate the transport property of a pure metal wire. The sp3d5 empirical tight-binding method is adapted to account for the full-band structure of the model [3].

RESULTS AND DISCUSSION

The specific contact resistivity and the system conductance are calculated (Fig. 2). The higher doping concentrations in the Si contact pad and lower Schottky barrier indeed result in a lower specific contact resistivity (Fig. 3). The measured specific contact resistivity starts increasing when the dimensions of the metal-semiconductor interface are smaller than 5nm in 2-D and increasing over an order of magnitude in the 3D case. (Fig. 2). The observed scaling effect of the specific contact resistivity can be explained by invoking the concept of the total transmission [4]. As a measure of conductance, the net current flowing from source to drain is computed as following equations,

$$I = \frac{2q^2}{h}\int dE \sum_n T(E)M(E)f(E_{FS} - E_{FD})$$

,where $2q^2/h$ is the quantum conductance. T(E) is the transmission probability, and M(E) is the number of transverse modes. Since a small bias, 10 mV, is applied across the device, the conductance can be expressed to $\Sigma T(E)M(E)$. The conductance decreases as the size of the metal wire decreases (Fig. 4 and Fig. 5). However, as the ballistic conductance of metal wire decreases linearly, the ρ_C is independent of the size of metal interconnect (Fig. 5). However, the reduced number of discrete modes across the Schottky barrier shows quantum confinement like effect in the contact pad region. The conductance between two different materials can be simply expressed to,

$$G = \frac{2q^2}{h}\int dE \sum_n T(E)\left(\frac{1}{\frac{1}{M_2(E)} - \frac{1}{M_1(E)}}\right)$$

When $M_1(E) >> M_2(E)$, the total system conductance depends on M_2. Hence, the interface downsaling, which means narrower carrier injection points in the contact pad, works as a bottleneck in the system. In addition, the structural mismatch ($W_M < W_{Si}$) causing wave function mismatch, and the mismatch effect leads transmission resonances generating fluctuations in the transmission lines (Fig. 4).

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CONCLUSION AND OUTLOOK

The key finding of this work is that the specific contact resistivity increases significantly when metal-Si contact dimensions drop below 5 nm due to the reduced number of discrete modes available for conduction across the Schottky barrier. The absolute magnitude of this scaling effect can be mitigated by reducing the Schottky barrier.

ACKNOWLEDGEMENT

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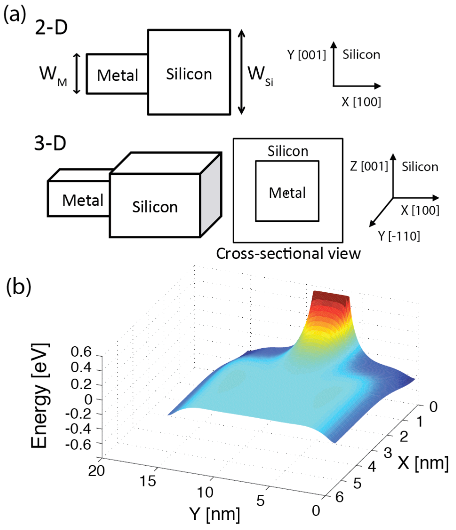

Fig. 1 (a) Schematics of the simulated contact structures (b) Potential profile of a contact model (W_M = metal-silicon interface width = 3 nm, W_{Si} = silicon width = 15 nm) and Schottky barrier height is set to 0.5 eV with $N_D = 2\times10^{20}$ cm^{-3}.

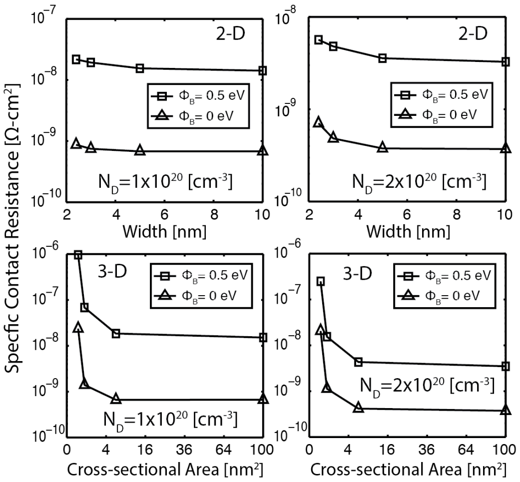

Fig. 2 Measured specific contact resistance for 2-D and 3-D structures for two given doping concentration N_D = 1×10^{20} cm^{-3} and 2×10^{20} cm^{-3} with Φ_B=0 eV sand 0.5 eV in semi-log scale. The dimension of metal wire is reduced from 10 nm to 2.4 nm while the dimension of contact pad is fixed at 15 nm in 2-D. The cross-section area of metal wire is varied from 10×10 nm^2 to 2.4×2.4 nm^2 in 3-D.

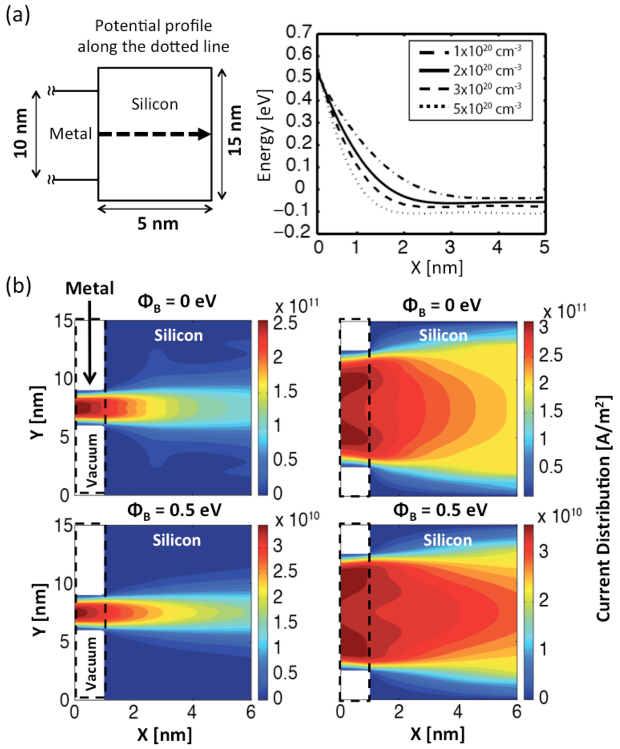

Fig. 3 (a) The potential profiles cut along the middle of structure in the transport direction in different doping concentrations (N_D = 1×10^{20} cm^{-3}, 2×10^{20} cm^{-3}, 3×10^{20} cm^{-3}, and 5×10^{20} cm^{-3}) with Φ_B = 0.5 eV (b) The current density spectrum from metal wire (W_M = 3 nm (left) and 10 nm (right) with fixed W_{Si} = 15 nm) to silicon pad with different Φ_B=0 eV and 0.5 eV and N_D = 2×10^{20} cm^{-3}.

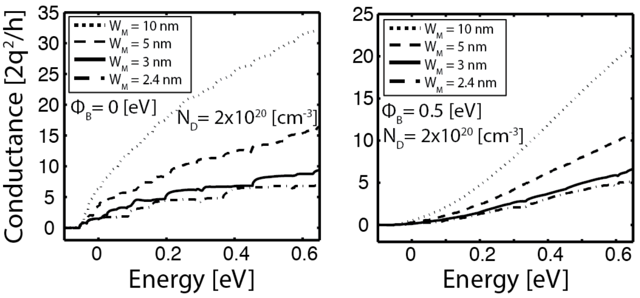

Fig. 4 Total transmission for 2-D structure (W_M = metal wire width, and W_{Si} = 15 nm) with Φ_B = 0 eV (left) and Φ_B = 0.5 eV (right) for N_D = 2×10^{20} cm^{-3}.

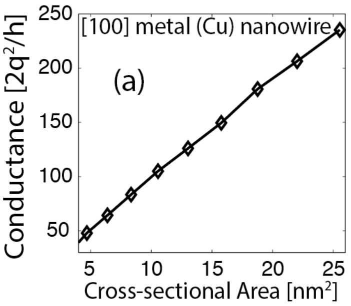

Fig. 5 The ballistic conductance of [100]-oriented Cu wires as a function of cross sectional area calculated using the sp^{3}d^5 tight-binding model.