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# Negative transconductance and gate position dependent behavior in axial-doped NPN SiGe nanowire transistors

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## Introduction

Nanowire transistors fabricated to date are typically undoped devices which rely on contact injection rather than NPN doping profiles. In order to engineer more useful devices such as diodes and tunneling field-effect transistors, a deeper understanding of doping profiles in nanowires is required. Few studies of P-N or N-P-N nanowires, or axial-junction wires with a specifically placed top gate, have been reported.

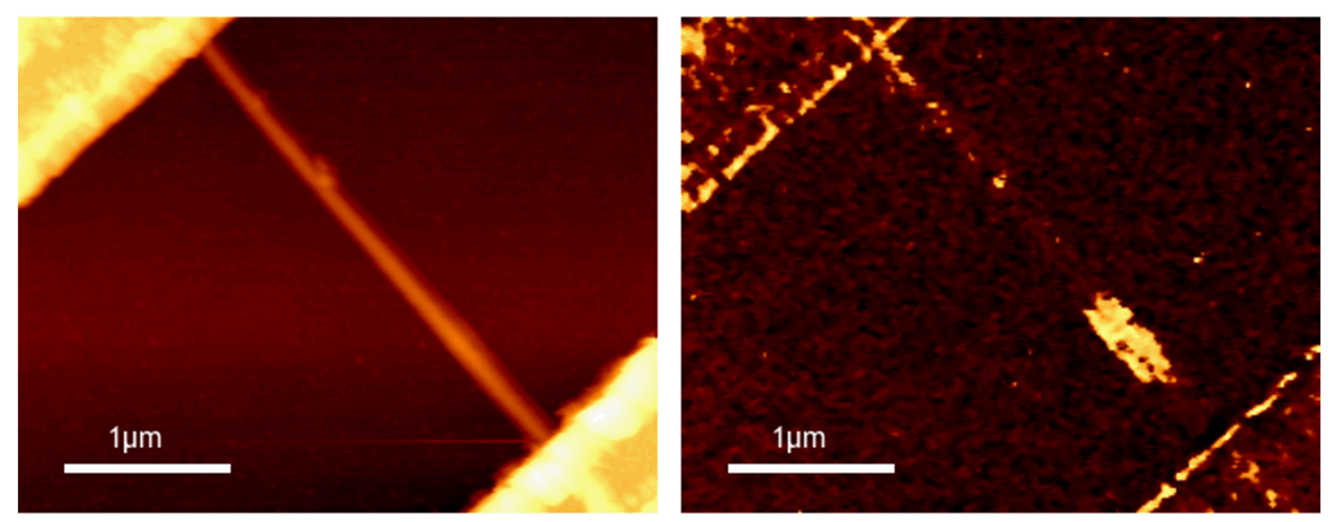
In this work, we consider N-P-N doped SiGe nanowire transistors with a top gate placed directly over the p-segment. The I-V behavior, conduction type, and on/off ratios are found to depend on position of the p-segment and gate along the channel. Carrier injection from contact into channel still plays a dominant role in these devices.

We also observe room-temperature negative transconductance (NTC) in a single-material (SiGe) system, due only to doping profile and contact proximity. Unlike these devices, other reported NTC devices have been more complicated heterostructures, or are negative resistance devices consisting of 2-terminal diodes which show higher current at lower temperatures.

## NPN-junction nanowires

Simple transistor structures were fabricated with an omega-gate structure placed over the p- segment of each wire.

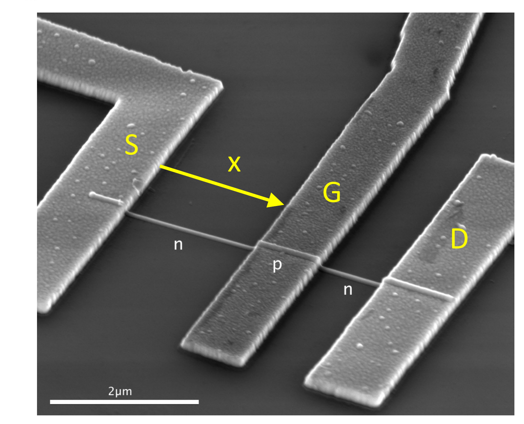
SiGe nanowires were grown with N-P-N doping profiles using the VLS method. After dispersing the wires onto silicon/$SiO_2$ substrates, source and drain contacts were patterned on each end of selected wires. A thin $Al_2O_3$ dielectric layer was then deposited by ALD. Then the n- and p- segments were located using scanning capacitance microscopy.

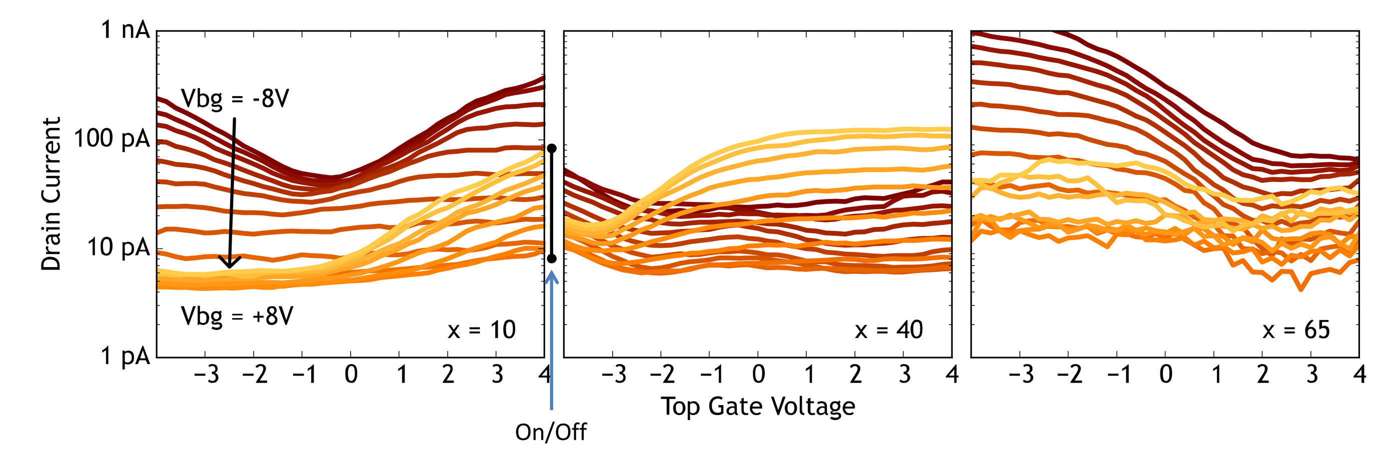



Height    Capacitance dC/dV

## Dual-gate Structure

Using the SCM images, a gate contact was fabricated directly over the p-doped segment. As the p-segments fall randomly between contacts, a set of devices with varying source-to-gate distances (x) were measured. The back-gate substrate was also biased simultaneously during measurement.

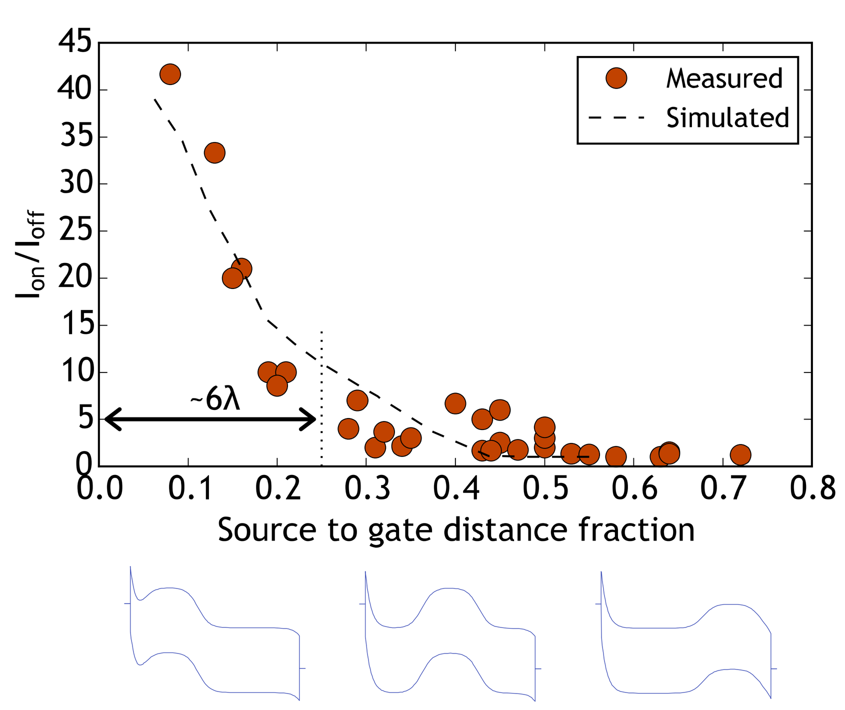


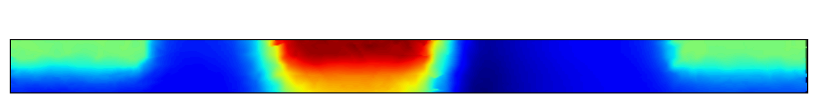

I-V curves depend on gate position along channel. Ambipolar behavior is present when the gate is near the source contact.

## On/Off Ratio and Simulation

On/Off ratios for electrons drop as gate moves away from source. Injection from source into channel is limiting resistance, and is assisted by gate proximity. When distance exceeds band-bending length, gate has little influence on current and on/off ratio approaches 1.

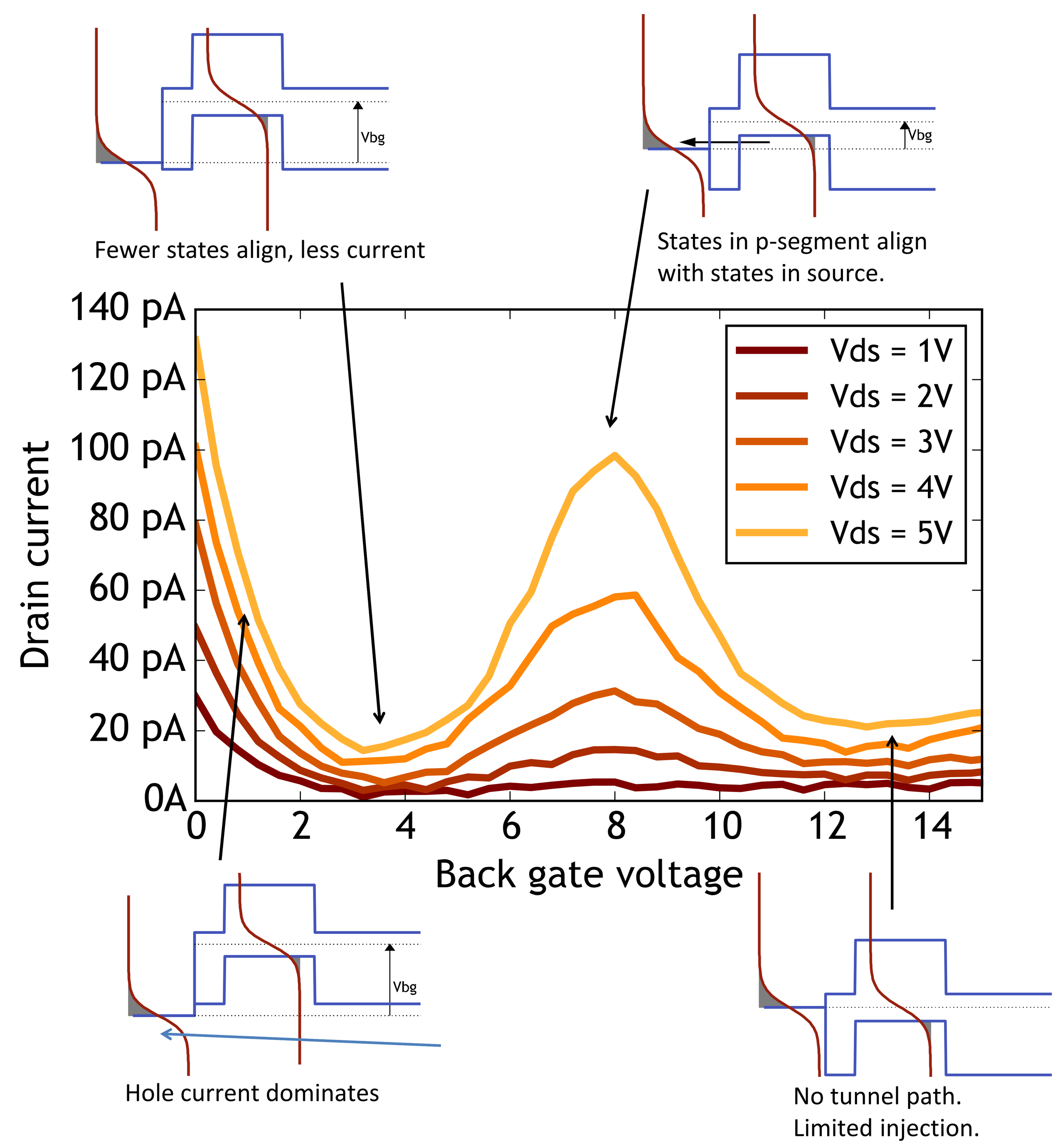


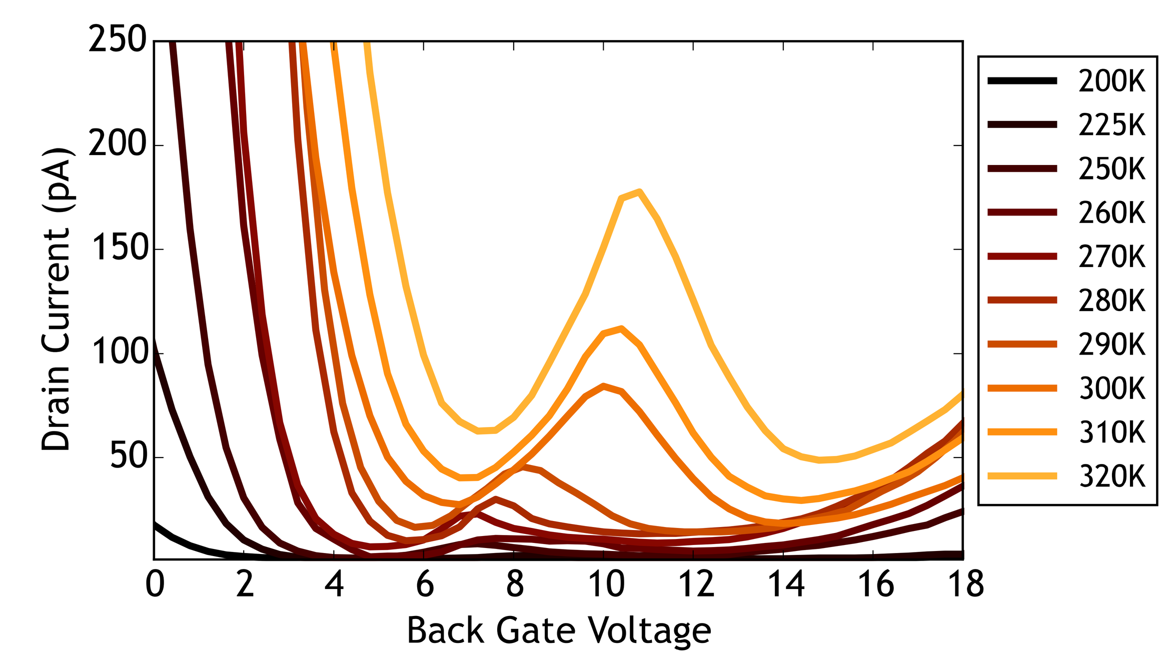

Behavior of on/off ratio is confirmed by COMSOL/Semiconductor simulation of this device structure (dotted line). Hole concentration for an example device and bias point is shown below.

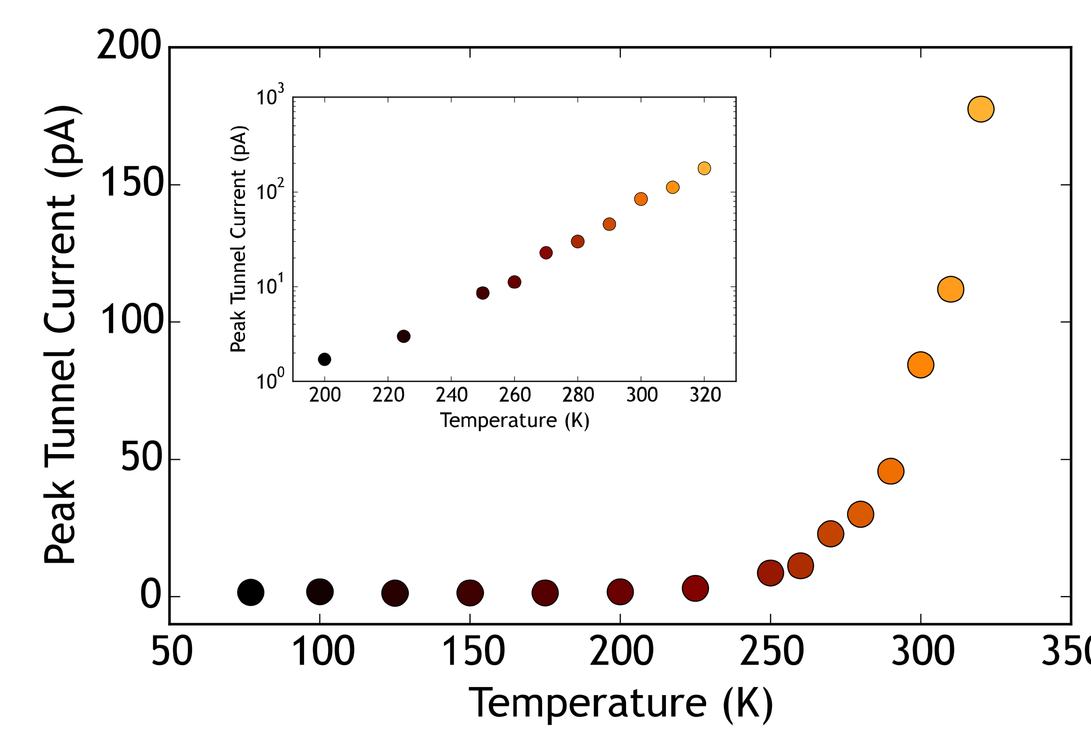



## Negative Transconductance

A few devices, with gate very close to source (within 50nm or less), exhibit negative transconductance, even when operated with back-gate only. NTC is due to tunneling directly from gate into source. Temperature-dependent measurements show NTC eliminated below 200K.

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