Towards High Performance Field-Effect Transistors with Bottom-Up Synthesized Graphene Nanoribbons

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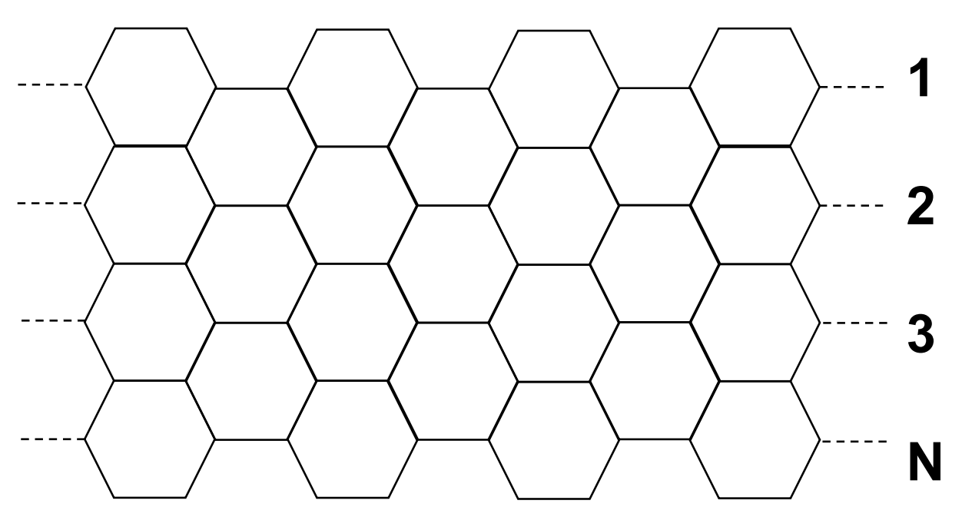
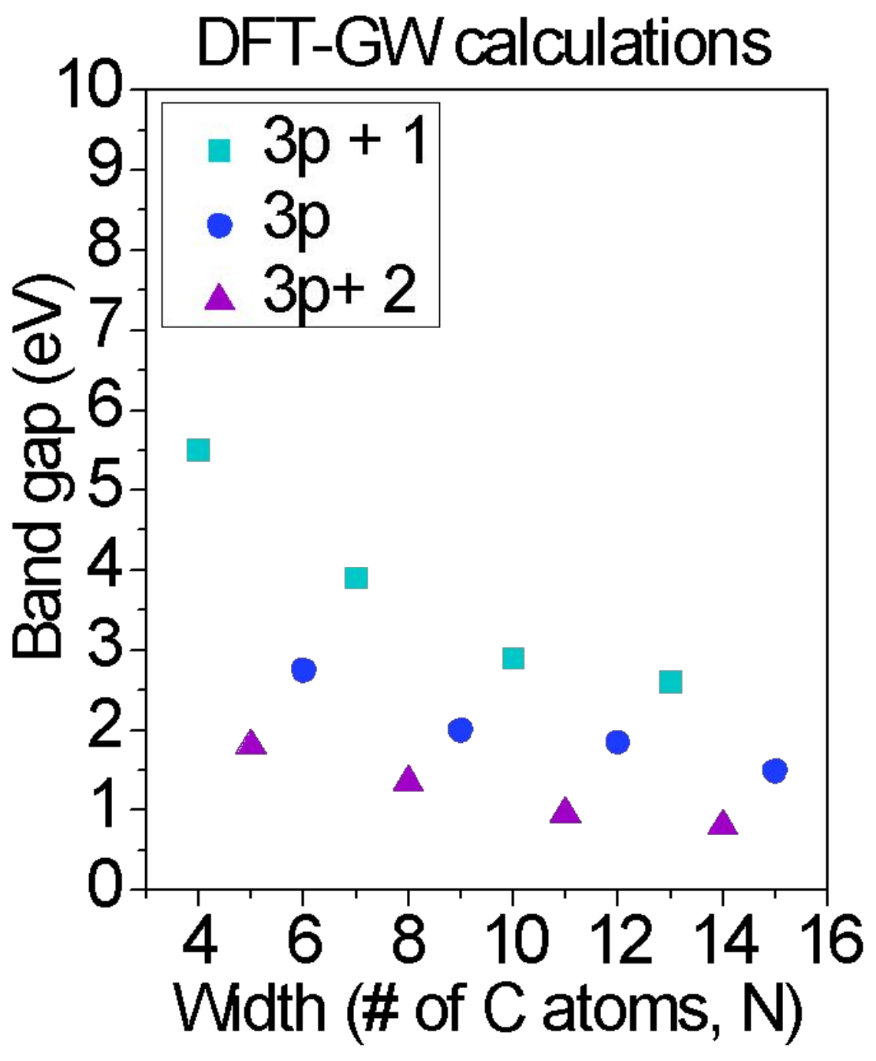
Abstract

Graphene nanoribbons (GNRs) can exhibit a uniform electronic band gap and emergent electronic properties that are promising for nano-electronic devices, such as field effect transistors (FETs), when synthesized with atomic precision. Bottom-up, on-surface synthesis approaches can provide the necessary precision to access these desirable properties, but the potential of these bottom-up synthesized GNRs for electronic devices has remained unexplored. Herein, we study the electrical properties of the FETs based on bottom-up synthesized nine-atom wide armchair GNRs (9-AGNRs) with varying channel lengths, a local back gate geometry of ~5 nm HfO_2 gate dielectric, and Palladium contacts. The GNR FETs exhibit high on-state current and excellent switching performance. The current-voltage characteristics indicate a strong correlation between the channel lengths and key performance metrics, such as subthreshold swing (*SS*), on current (I_{ON}), and on/off current ratio (I_{ON}/I_{OFF}). The present work provides important insights into the design of high-performance graphene-based electronic devices.

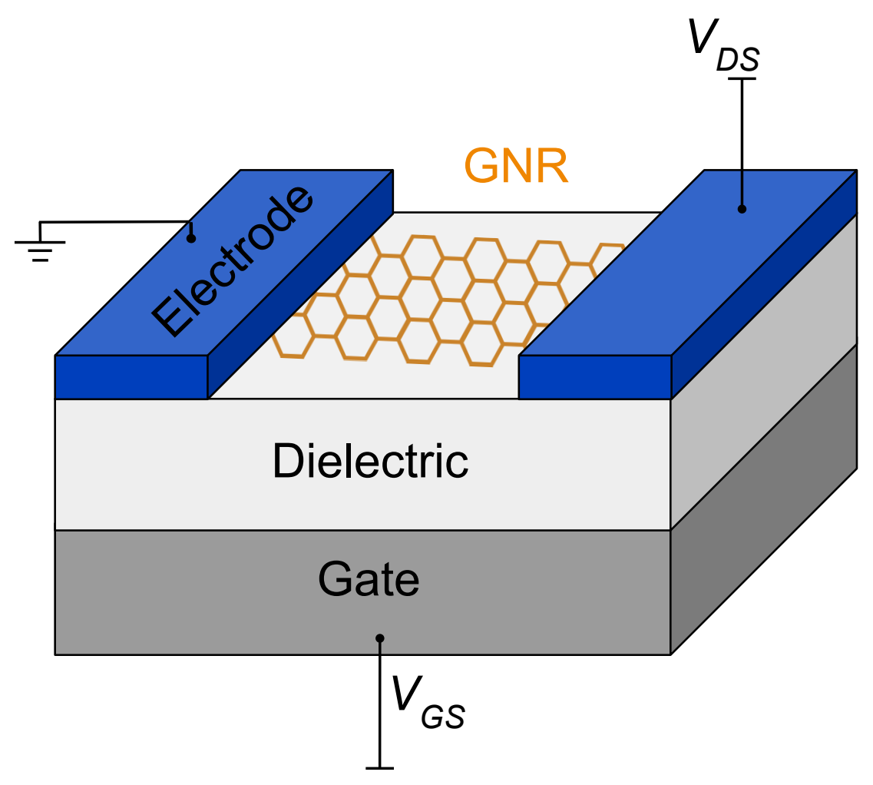
Introduction

- **Motivation:** Bottom-up synthesized ultranarrow (0.95 nm) 9-AGNRs with a theoretical band gap of 2.10 eV, a theoretical I_{ON} of 30 μA, and a theoretical I_{ON}/I_{OFF} of > 10^6 is a promising transistor channel material for future transistor technologies.[1,2]
- **Problem:** The experimental results obtained for 9-AGNR FETs are much lower than the theoretically predicted values.[3,4,5]
- **Goal:** This study aims to understand the impact of the device geometries, especially channel lengths, on the GNR FET device performance.
- **Broader impact:** This understanding would help pinpoint the improvements needed to realize GNR FET metrics close to the projected values for high performance logic applications.





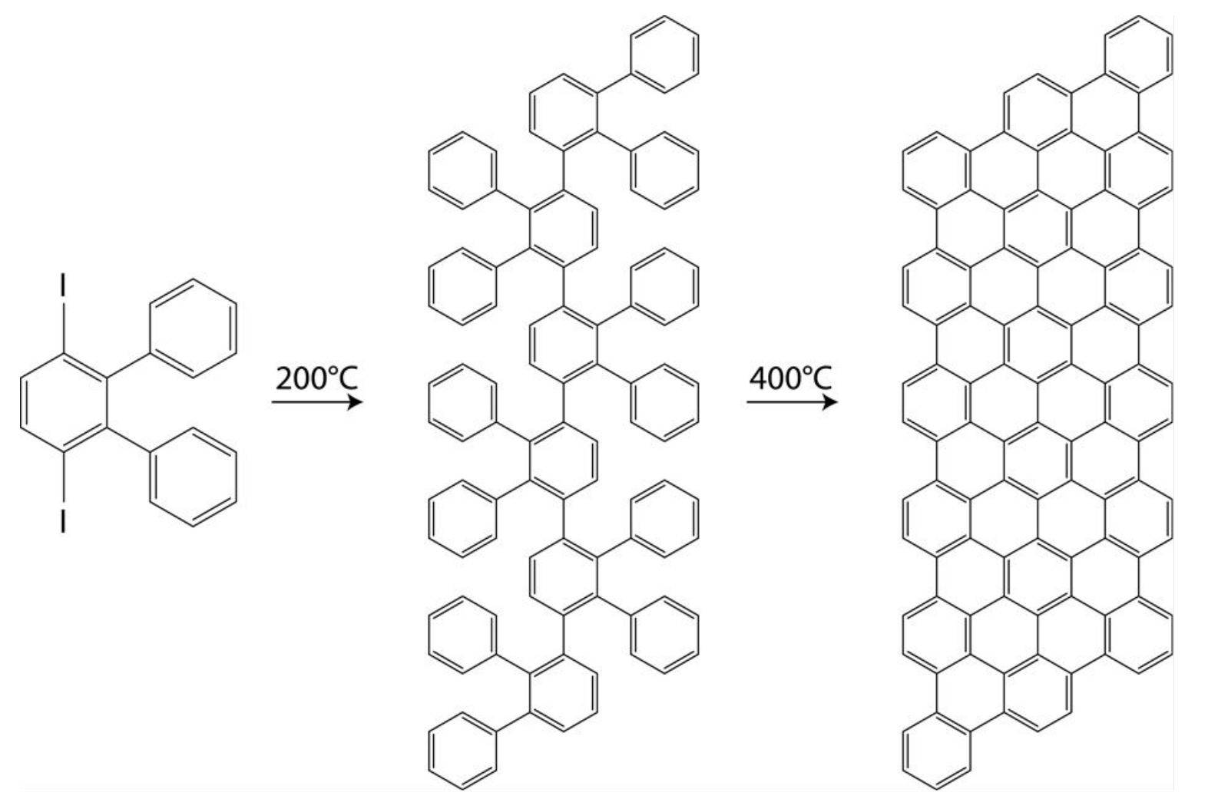
Inverse relationship of armchair GNR width and bandgap.



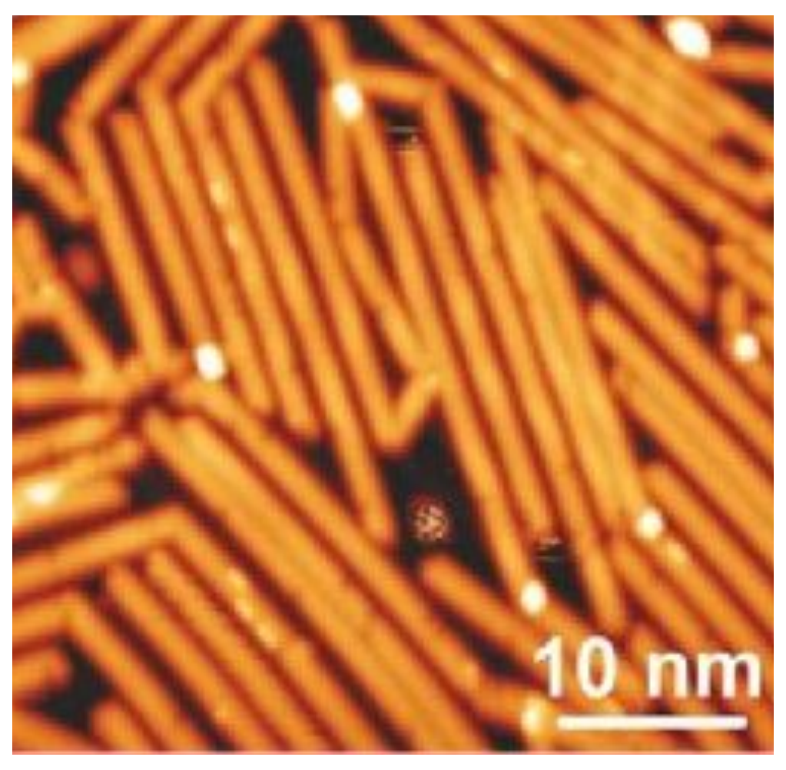
Device schematic of a GNR FET

Methods

Bottom-up synthesis

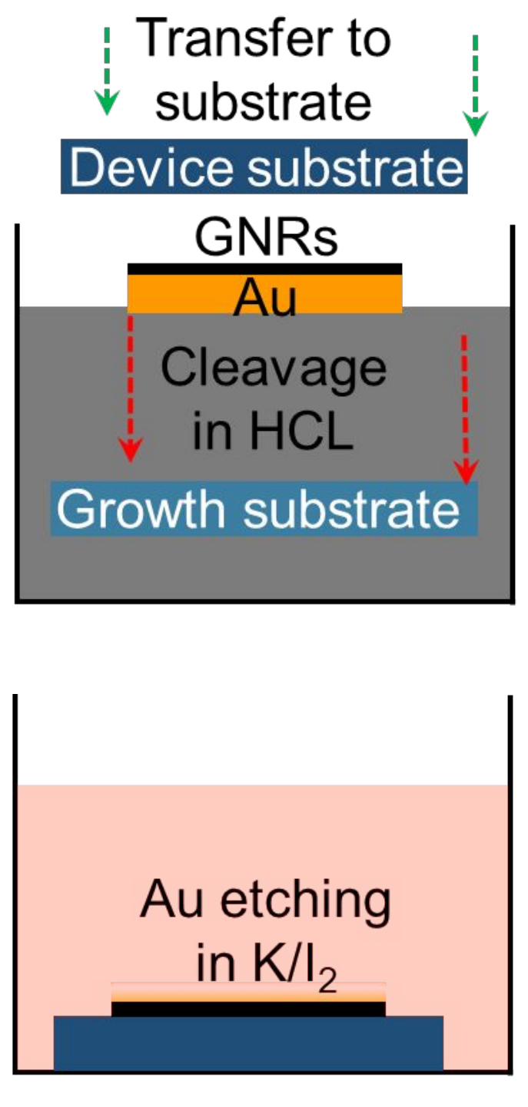


Reaction paths for 9-AGNR growth on Au(111)[6]



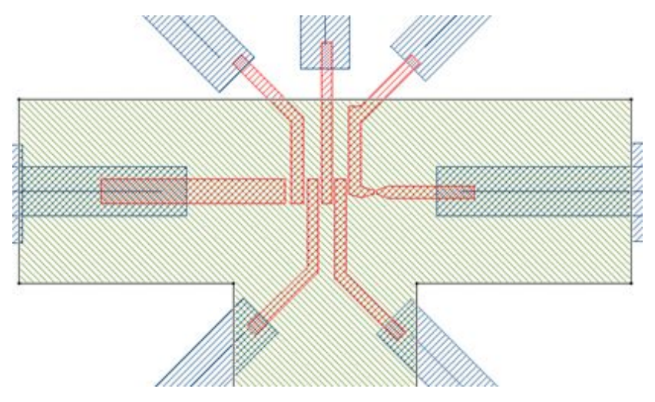
STM imaging of 9-AGNRs on Au(111)[6]

GNR Transfer and device fabrication

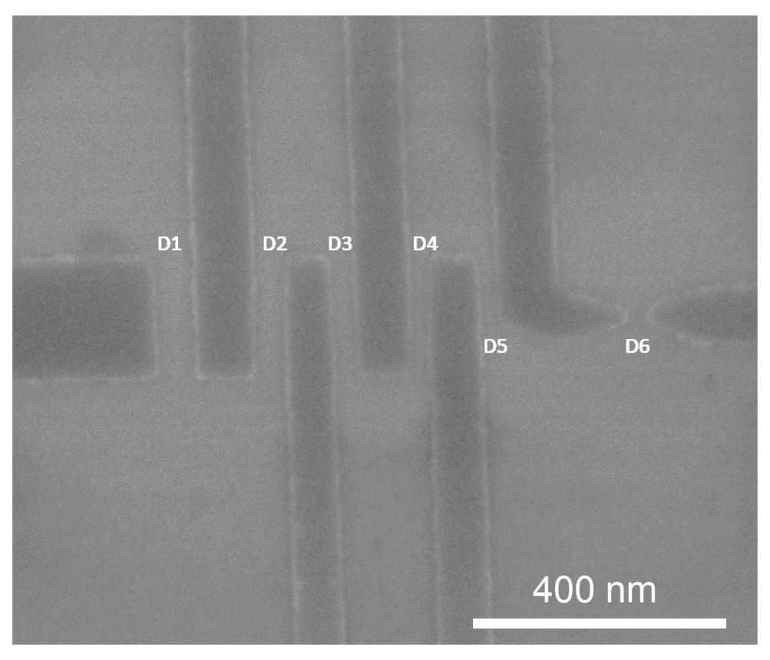


Wet-transfer process[4]

Cross-sectional diagram of a back-gate GNR device



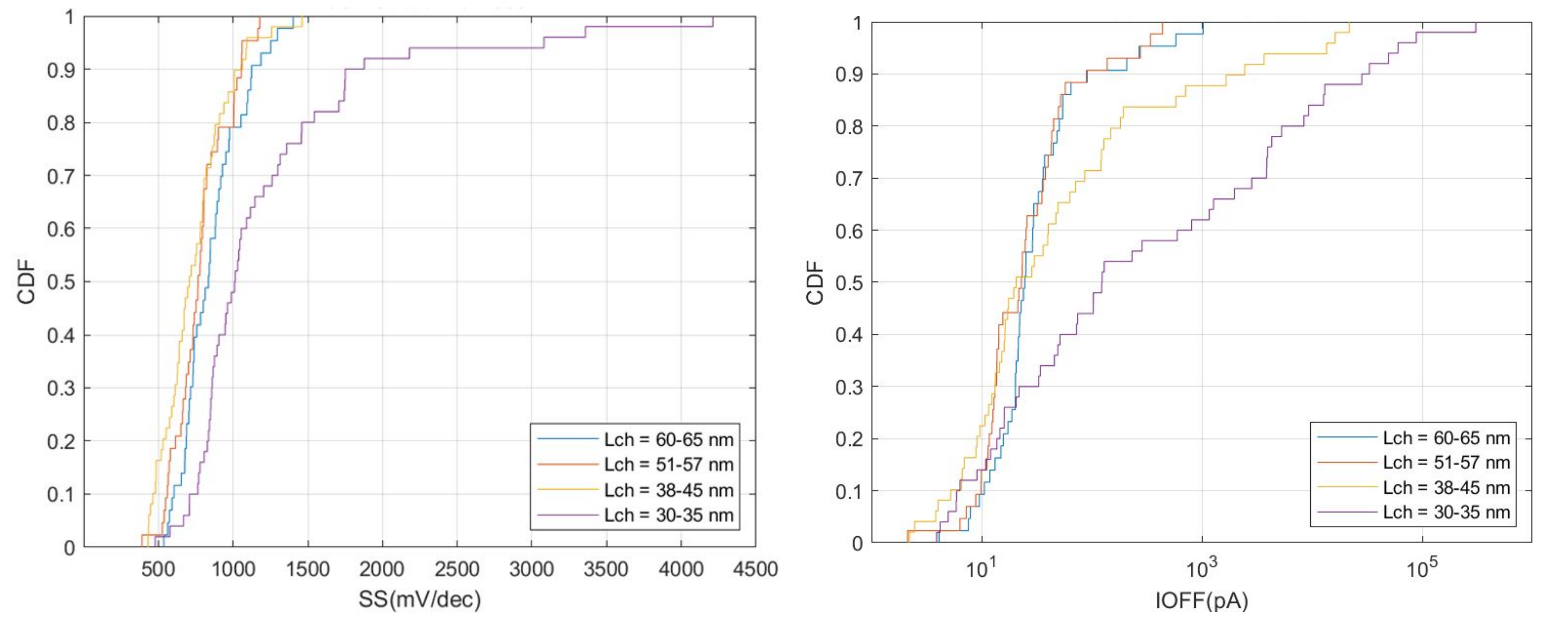
Device layout



SEM image of a GNR FET device

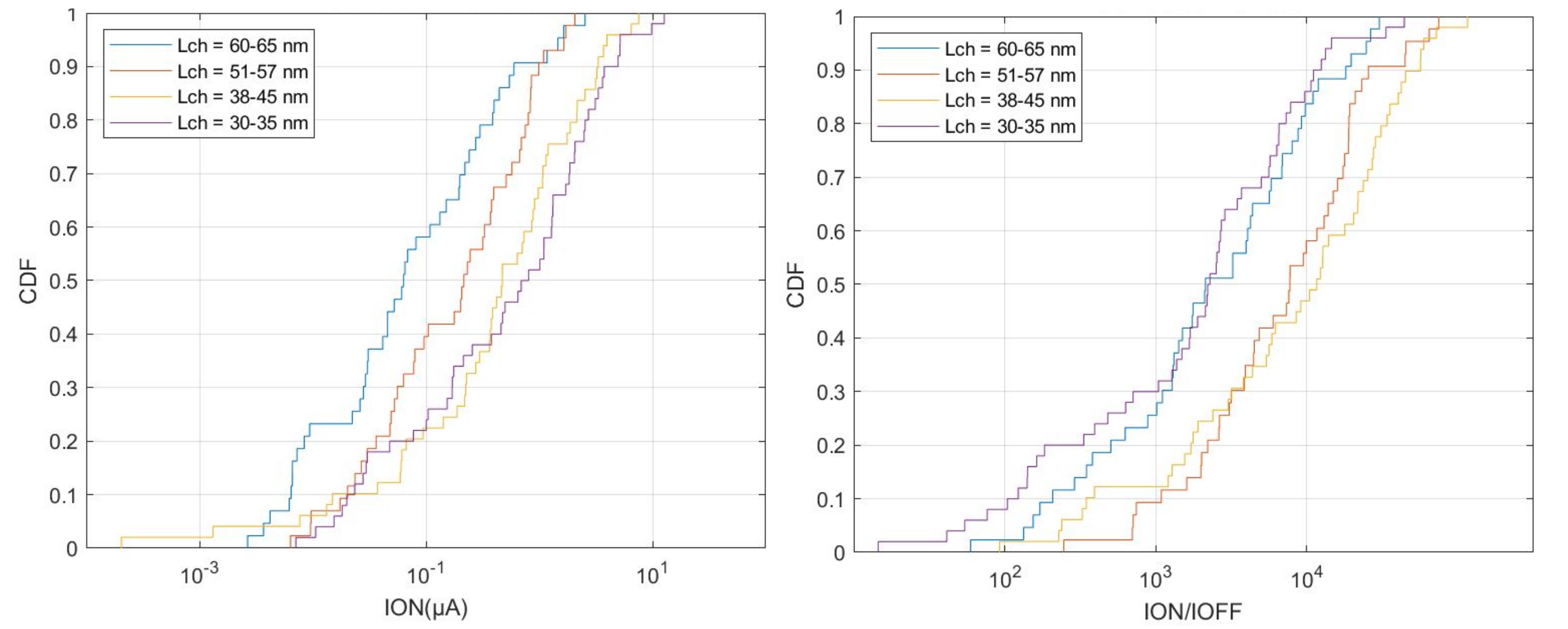
Results

Subthreshold swing and off-state current performance



- The short channel devices suffer from high *SS* and I_{OFF}.

On-state current and switching performance



- While the short channel FETs exhibit highest I_{ON}, both the shorter and longer channel devices suffer from low I_{ON}/I_{OFF}.

Conclusions

- ✔ The influence of L_{ch} on the device performance revealed by this study elucidates the need to reduce and improve short channel effects, GNR-GNR screening, and contact resistance.
- ✔ Future studies should focus on exploring the impact of synthesis techniques, varied device geometries and channel width on GNR integrity and GNR FET device performance.
- ✔ These areas of focus will help realize the promise for GNRs as a transistor channel material in future high performance logic applications.

References

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