Bow-Tie Antenna Enhanced Terahertz Spectroscopy on Single III-V Semiconductor Nanowires

Nicholas Morgan, Martin Friedl, Simon Escobar, Elias Stutz, Anna Fontcuberta i Morral

Department of Materials Science and Engineering, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

LABORATOIRE DES MATERIAUX SEMICONDUCTEURS

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Motivation

Nanowire structures offer the possibility to integrate high-mobility, direct-bandgap III-V semiconductors with the mass-manufacturability of CMOS systems, opening the door to more sophisticated, higher performance electronic and optoelectronic devices. Reliable characterization of nanowire electronic properties is difficult due to their geometry and dimensions. Terahertz (THz) spectroscopy is an effective tool for detailed and reliable study of charge carrier dynamics in ensembles of semiconductor nanowires. With this project, we explore the possibility of extending the technique to single nanowires by using bow-tie antennas for THz field enhancement.

Antenna Fabrication

Antennas were fabricated on a fused silica substrate using photolithography and metal evaporation to form alignment markers, drop-casting the GaAs/AlGaAs core-shell nanowires suspended in IPA onto the substrate, using optical microscopy and in-house software to localize the nanowires and generate the antenna design, and finally using e-beam lithography, metal evaporation and liftoff to complete the device. The process flow and subsequent SEM micrographs are shown below.

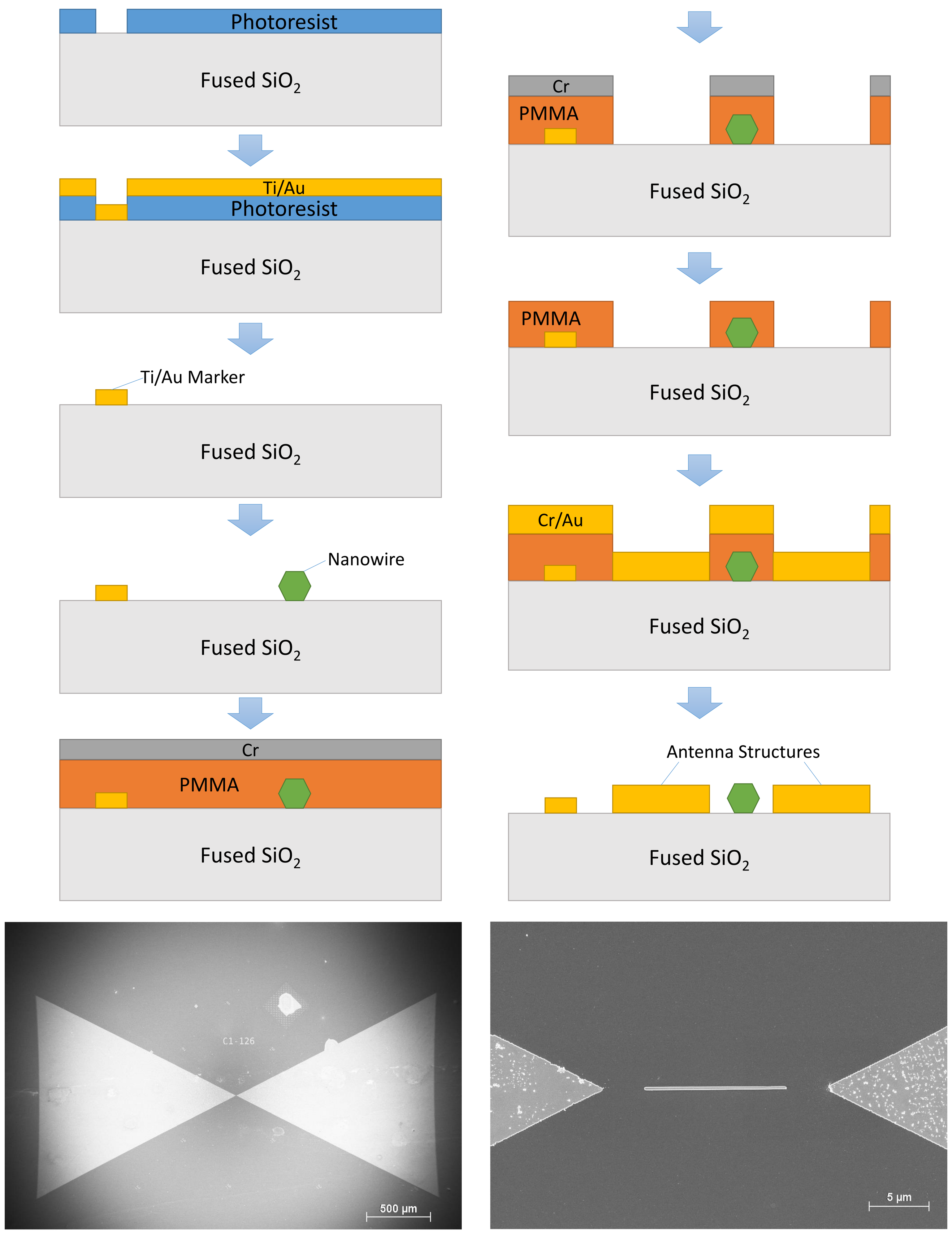

Figure 1: Process flow for antenna fabrication and resulting SEM images of one device.

Terahertz Spectroscopy

THz spectroscopy was performed on the antenna-nanowire devices. The technique consists of measuring the transmission of a THz pulse through the sample. The absorption by the sample is inversely proportional to its complex conductivity, and subsequent modeling can be used to determine electronic properties such as mobility and charge carrier lifetime. Unfortunately, no signal was detected for any sample, indicating that the antenna's field enhancement is insufficient.

Raman Spectroscopy

Raman spectra of the nanowires were collected in a backscattering configuration using 532 nm exciting light, using defocused light to compare nanowires with and without an antenna and assessing the polarization sensitivity for a focused versus defocused beam.

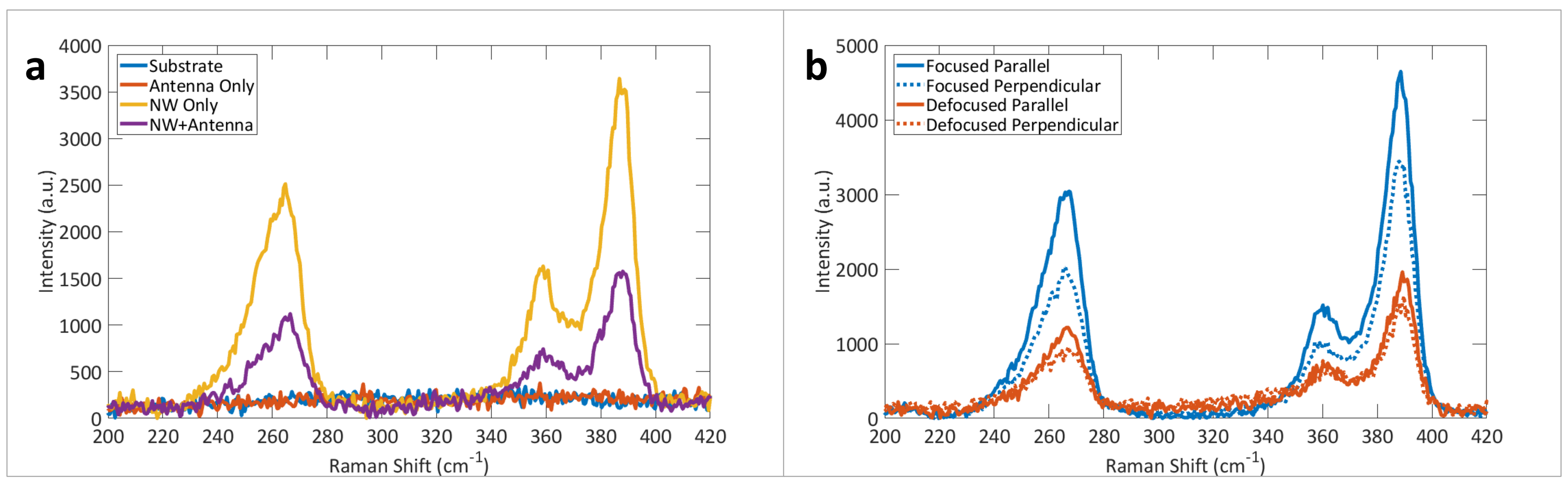

Figure 2: a) Raman spectra for fused silica substrate, reference antenna with no nanowire, GaAs/AlGaAs nanowire with no antenna and similar nanowire with antenna. b) Focused and defocused polarization-dependent Raman spectra.

FDTD Simulations

Finite-difference time-domain (FDTD) simulations were performed to study the field enhancement around the nanowire as a function of frequency for different antenna sizes, angles and tip rounding.

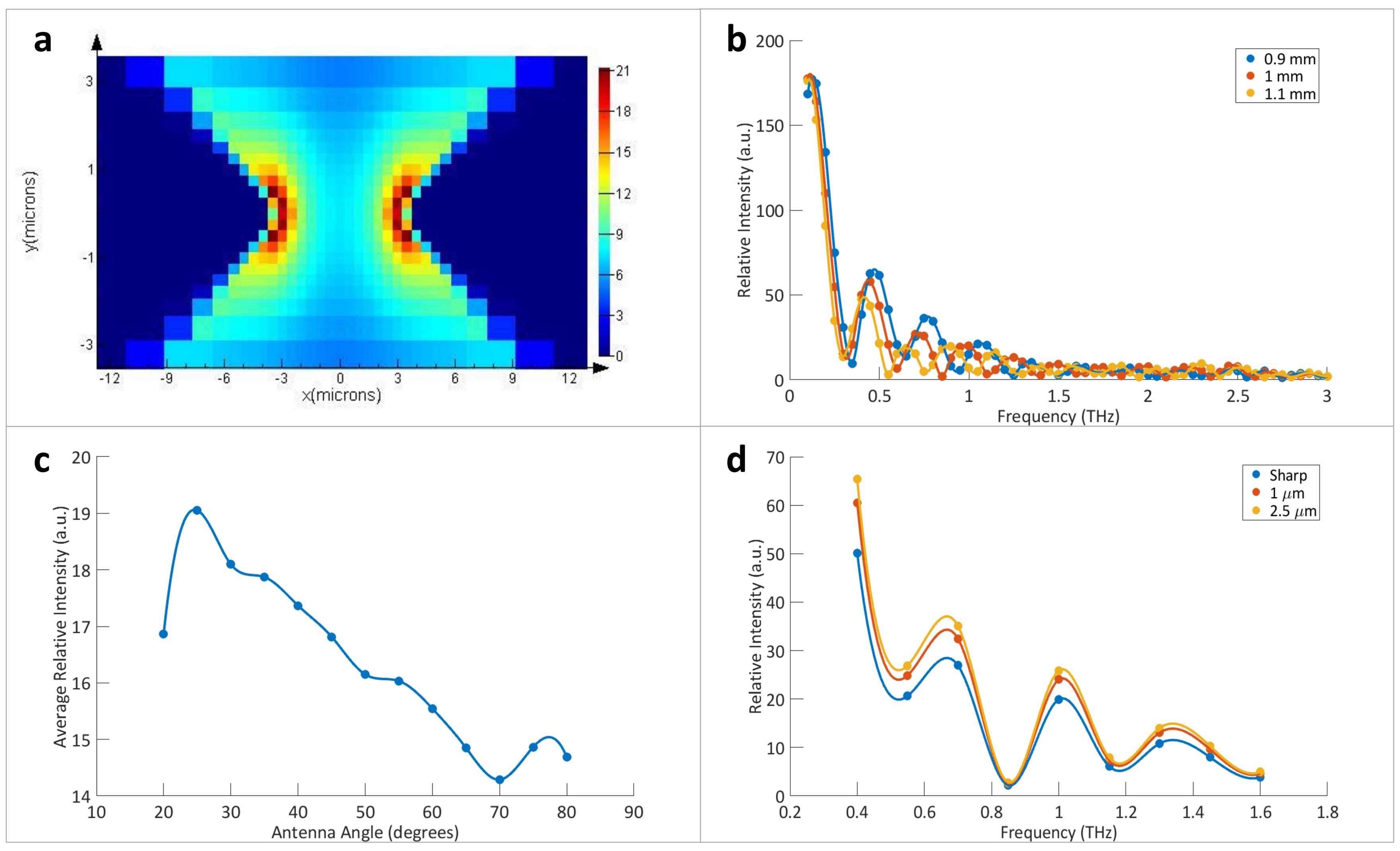

Figure 3: a) Spatial map of field enhancement at antenna tip for a frequency of 1 THz. b) Field enhancement as a function of frequency for three antenna sizes. c) Average field enhancement from 0.4 – 1.6 THz as a function of antenna angle. d) Field enhancement as a function of frequency for sharp and rounded antenna tips. Legend gives radius of curvature at tip.

Conclusions

Initial devices gave no signal when measured by THz spectroscopy, indicating that antenna design optimization is needed. Raman spectroscopy of two nanowires indicates that the antennas may result in decreased Raman scattering intensity and polarization sensitivity. FDTD modeling suggests that THz field enhancement can be improved by making smaller antennas with angles of 25 degrees and rounded tips. Additionally, the antenna tips should be as close to the nanowire as possible. The proposed changes are simple to make and provide a possible path toward achieving THz spectroscopy on single III-V semiconductor nanowires.

Acknowledgements

I would like to give thanks to all of those who made this work possible, including my supervisor Anna Fontcuberta i Morral, the other students in LMSC, specifically Martin Friedl, Simon Escobar, Elias Stutz and Lucas Güniat, our collaborators at Oxford University, Djamshid Damry and Professor Michael Johnston, and the CMi staff.