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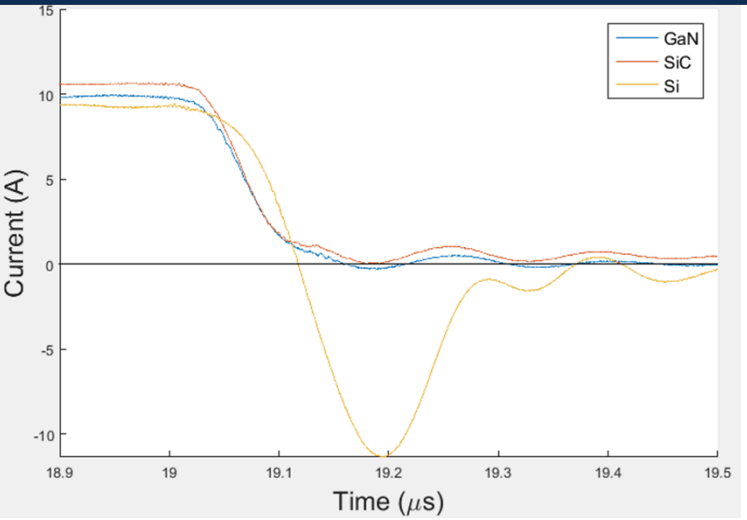

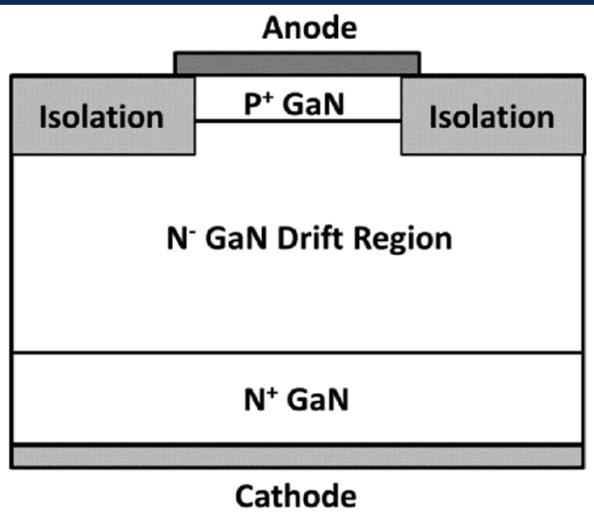

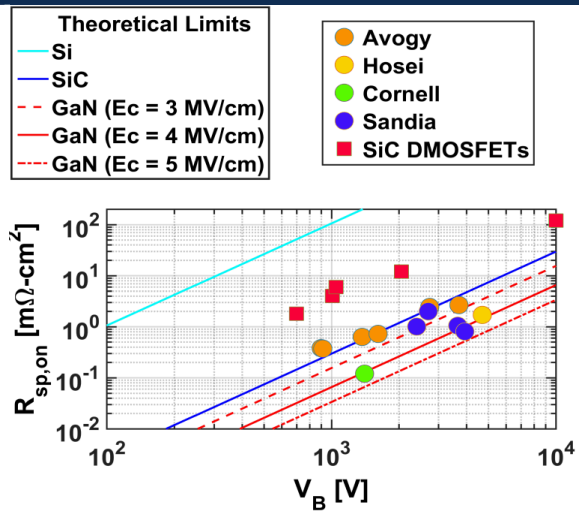

Switching Characterization of Vertical GaN PiN Diodes

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Contents

- Motivations
- Approach
  - Testing
  - Data Processing
- Results & Observations
- Conclusions & Next Steps

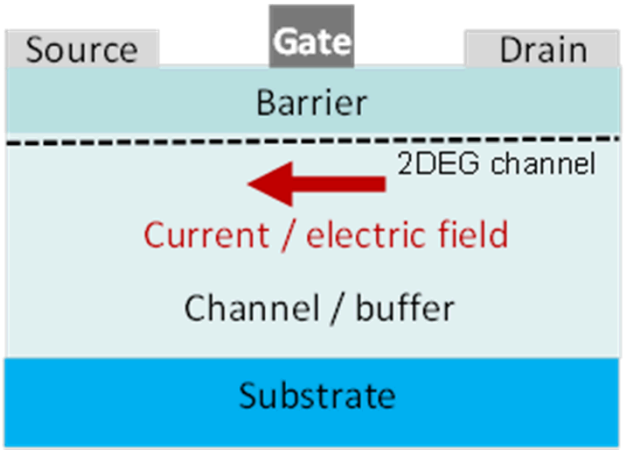
Motivation

For mature Si technology, most power device reliability focus on the packaging and thermal management

- Devices are mature and well-understood

For WBG materials, devices are maturing

- Materials are much newer
- Both SiC and GaN have reached relative maturity
- Vertical GaN devices are now emerging



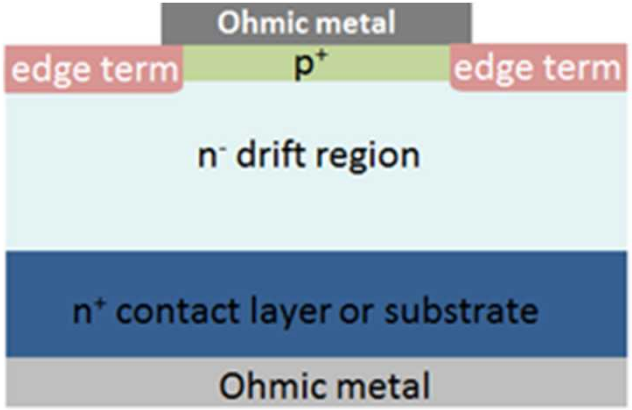
Focus on newly developed vertical GaN devices

Historically, GaN devices in lateral orientation

- Low breakdown voltage (<600 V) due to electric field management
- No avalanche breakdown has been reported

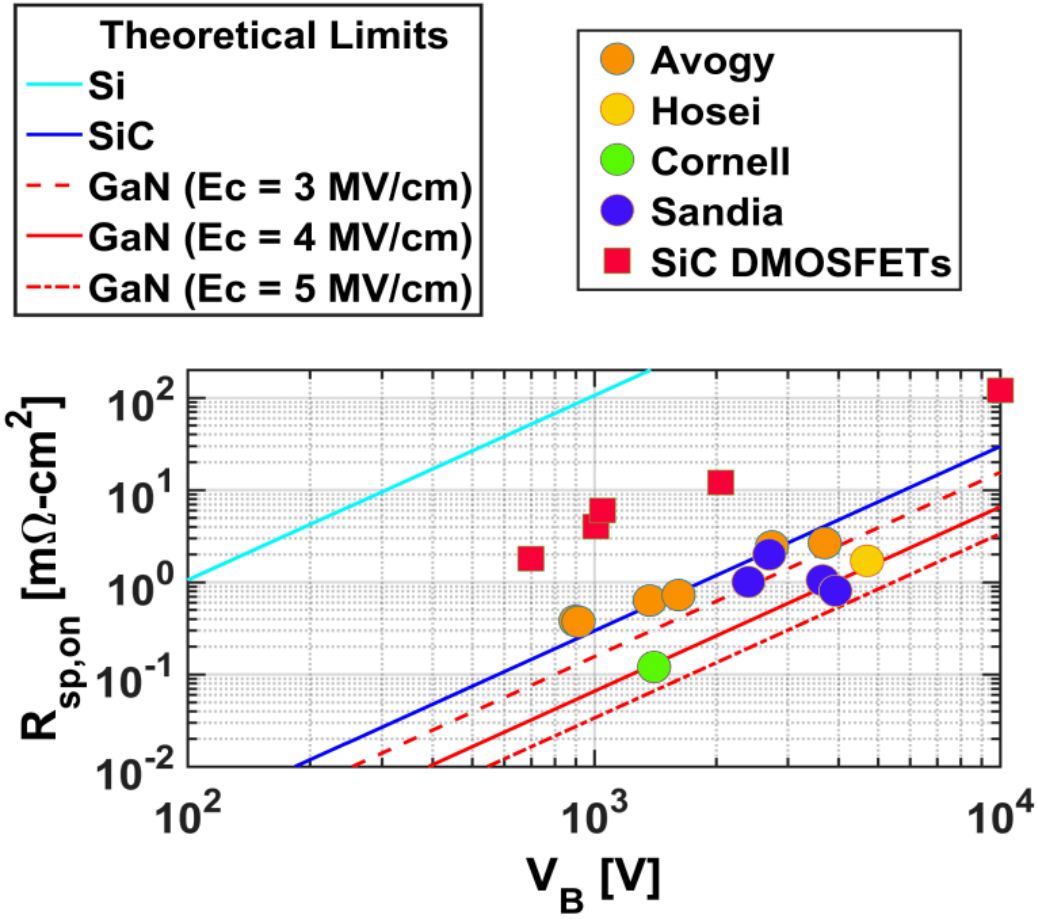
Vertical GaN (v-GaN) devices are now becoming available

- Reliability and switching performance are ***uncharacterized*** in literature
- Breakdown voltage and avalanche breakdown capability has been reported



Advantages of Vertical Devices

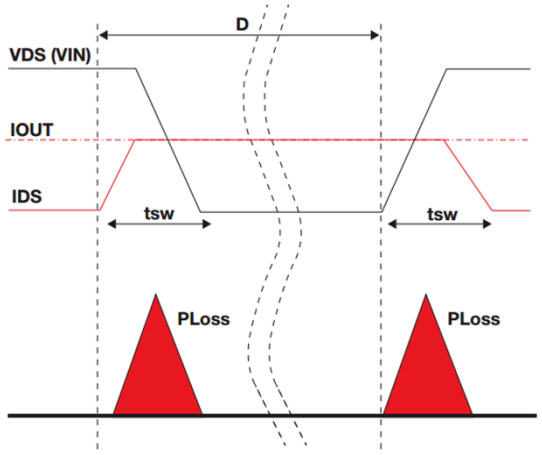
- Vertical devices and the FOM
- High breakdown
- Avalanche ruggedness
- Provides avenue to GaN at high voltages



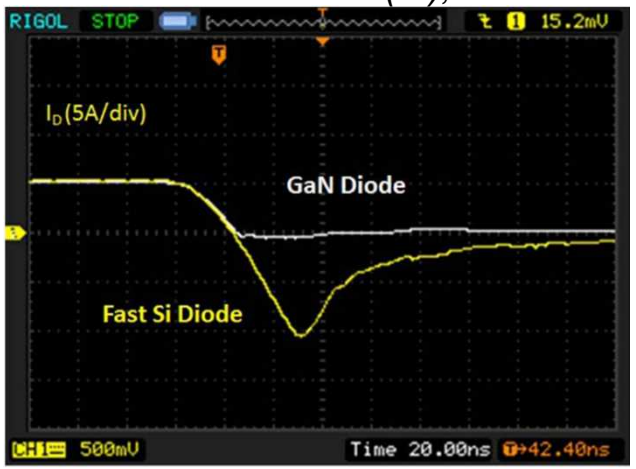
Why Switching Characterization?

- Leading loss in Si devices
- Fast switching can lead to L/C size reduction
- Little switching characterization on v-GaN diodes

	Current		Proposed
Technology	Si IGBT	Si Thyristor	WBG
Voltage Rating	6.5 kV	10 kV	100 kV
Switching Time	400 µs	100's µs	0.1 µs
Switching Frequency	20 kHz	60 Hz	10 kHz
Switching Loss (J/switch)	10	100	2
System Cost ($/MW)	$230,000-$500,000		$100,000



Mehta (TI), 2015

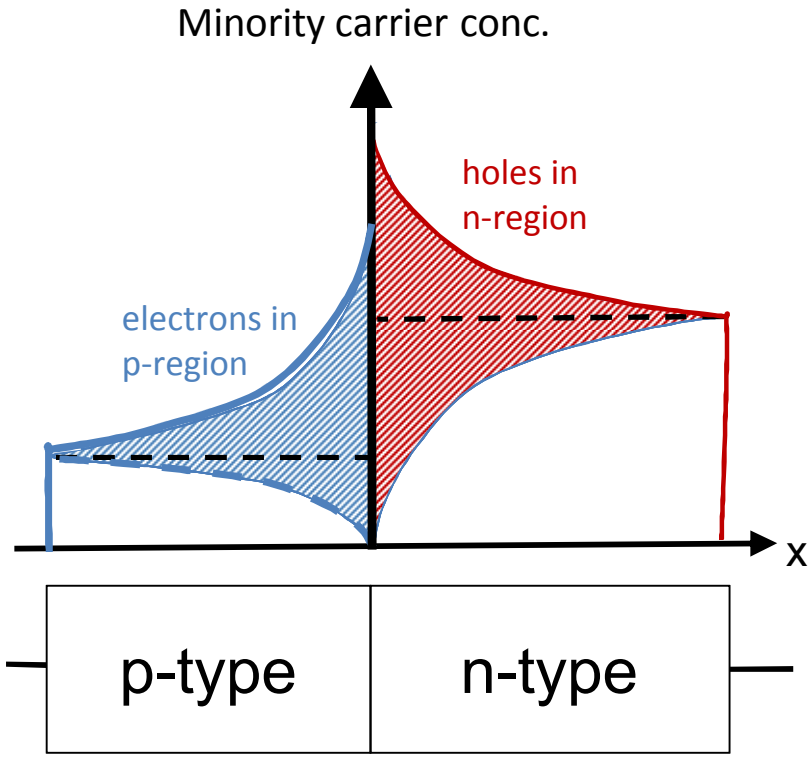


Kizilyalli et al., 2013

Reverse Recovery

- For diodes, energy loss during switch transitions due to reverse recovery
- As diode goes from **conducting** to **blocking** state

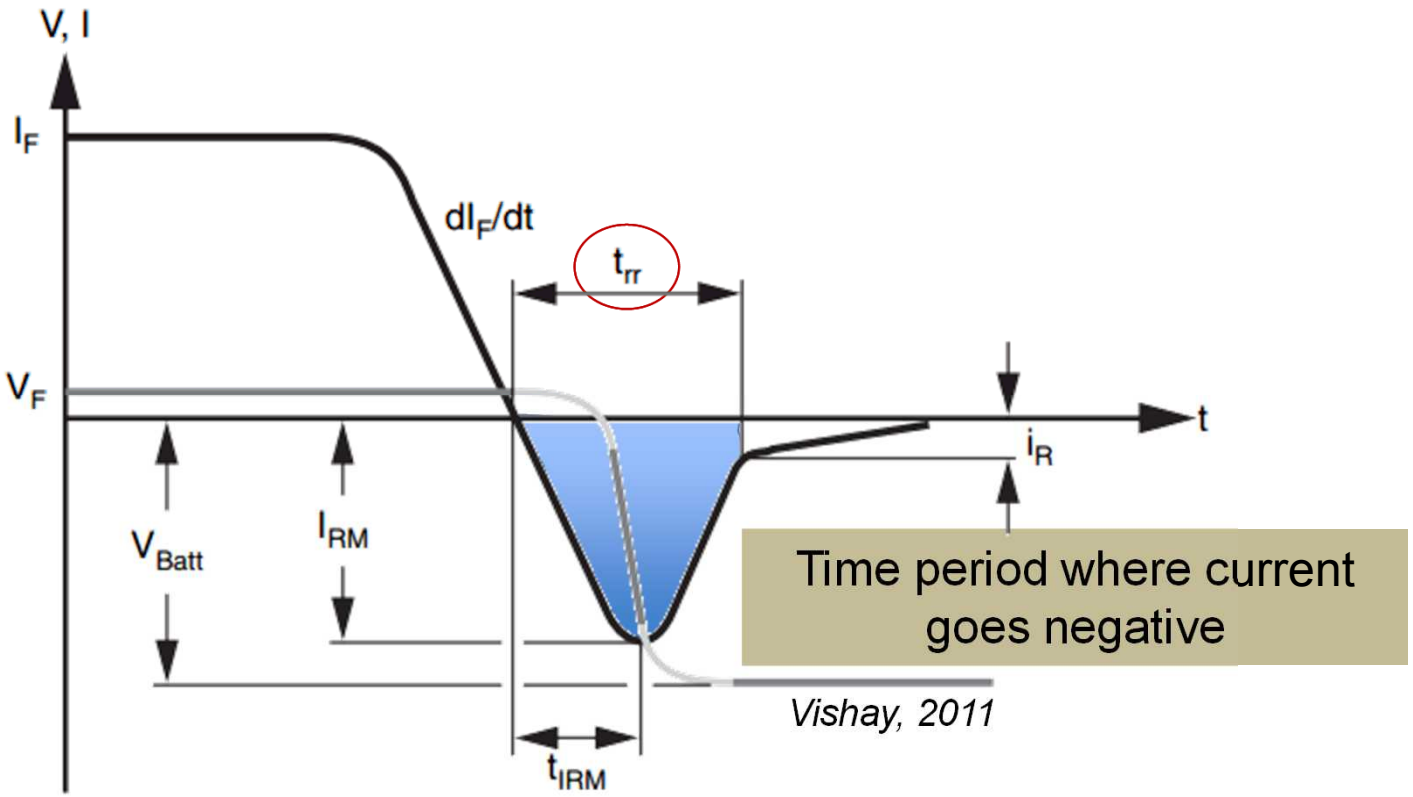
- Change in charge distribution between conducting and blocking states
- Must dissipate extra charge
- Requires reverse current flows until mobile charge in junction is depleted
- Time depends on junction capacitance and carrier lifetime



- Schottky diodes have no reverse recovery

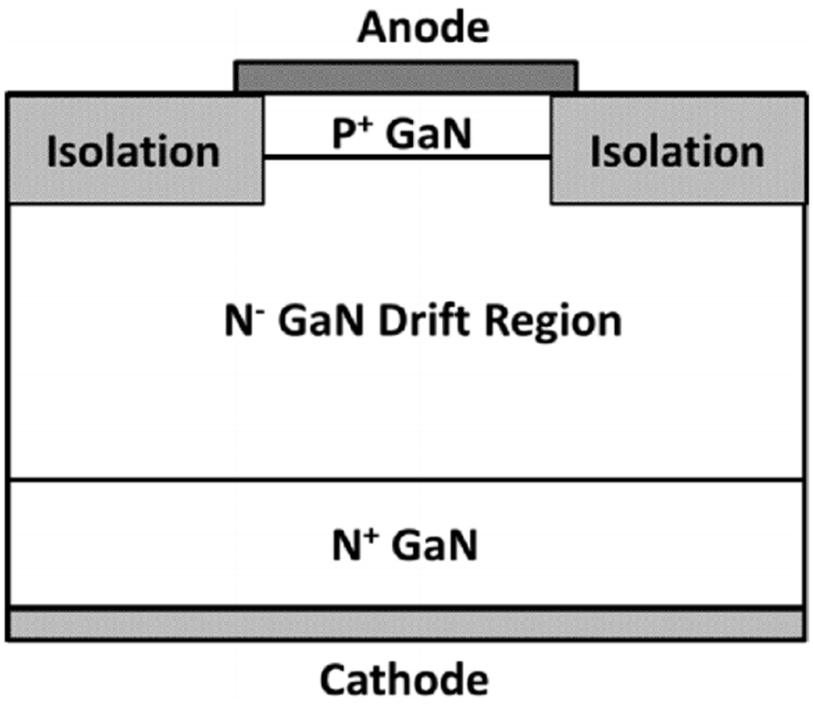
The Reverse Recovery Period

- As diode goes from **conducting** to **blocking** state
  - Current goes negative for period of time



Device Background

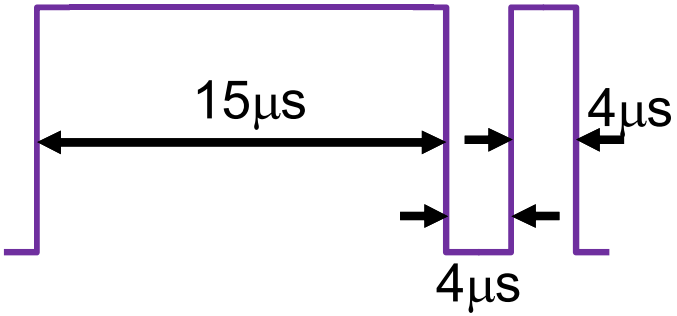
- Avogy AVD05120 GaN Diode
- True vertical device
  - GaN device on GaN substrate
- Rated for 1200V and $100A_{PULSED}$
- Traditional Power Diode configuration

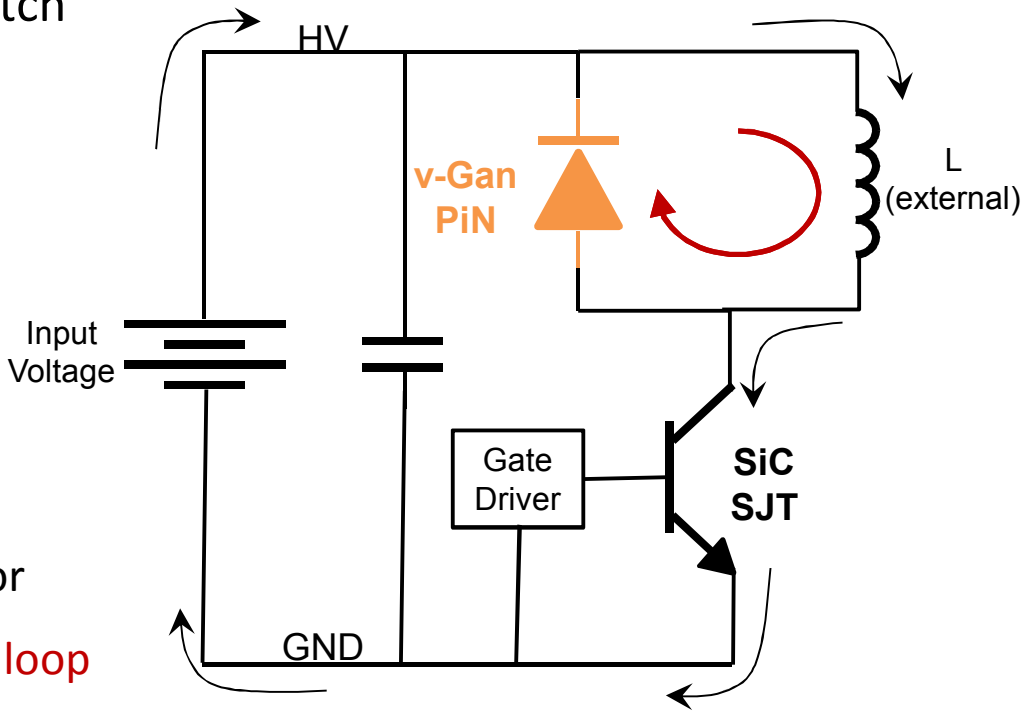


Kizilyalli et al., 2013

Test Circuit and Stimulus

- To Test diode reverse recovery used a Double Pulse Test Circuit
- Simple circuit (diode, switch, and inductor)
  - Allows for high voltage, low current power supply to apply high voltage/current to diode and switch
- Gate signal is a double pulse





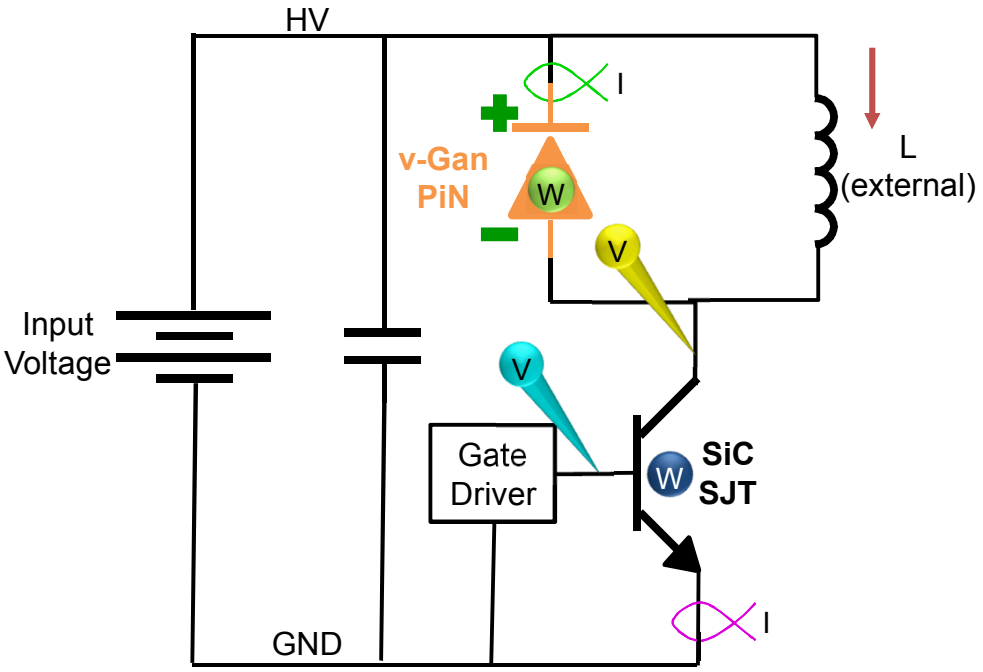
1st pulse: Increased stored energy in inductor

1st off: flow current through diode/inductor loop

2nd pulse: discharge high current/voltage through switch

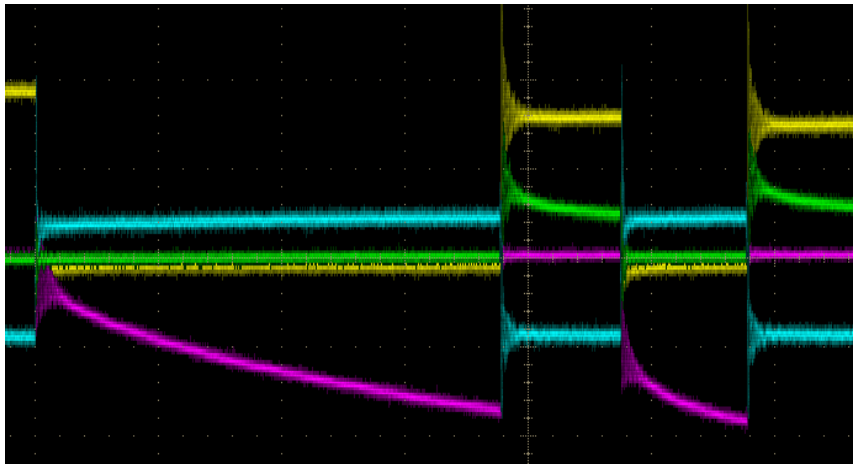
Measurement Setup

- Measured
  - V_{GS}
  - V_{DS}
  - I_{DS}
  - I_{Diode}
- Derived
  - V_{Diode}
  - I_L
  - P_{DS}
  - P_{Diode}



Handling the Data

- Limited measurement resolution
  - Rogowski coil used to measure diode current
  - Voltage measurements off of test points



- MATLAB
  - Applied FFT filter
  - Truncated data to reduce complexity

```
%% Filtering
% Define low-pass filter parameters
Fpass = 5;
Fstop = 30;
Ap = 1;
Ast = 30;
Fs = 10000;

% Apply filter to data
v_DSf = myfilter(v_DSo, Fpass, Fstop, Ap, Ast, Fs);
v_GSf = myfilter(v_GSo, Fpass, Fstop, Ap, Ast, Fs);
i_Df = myfilter(i_Do, Fpass, Fstop, Ap, Ast, Fs);
i_diodef = myfilter(i_diodeo, Fpass, Fstop, Ap, Ast, Fs);
```

Obtaining the Desired Information

- Calculated diode voltage, inductor current, and power through diode and transistor

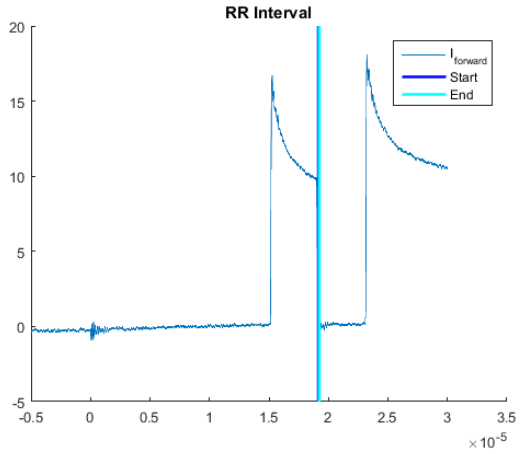
```
% Diode Voltage
v_diodeo = V_DD - v_DSo;
v_diode = V_DD - v_DS;

% Inductor Current
i_Lo = i_Do + i_diodeo;
i_L = i_D + i_diode;

% Transistor Power
P_DSo = v_DSo.*i_Do;
P_DS = v_DS.*i_D;

% Diode Power
P_diodeo = v_diodeo.*i_diodeo;
P_diode = v_diode.*i_diode;
```

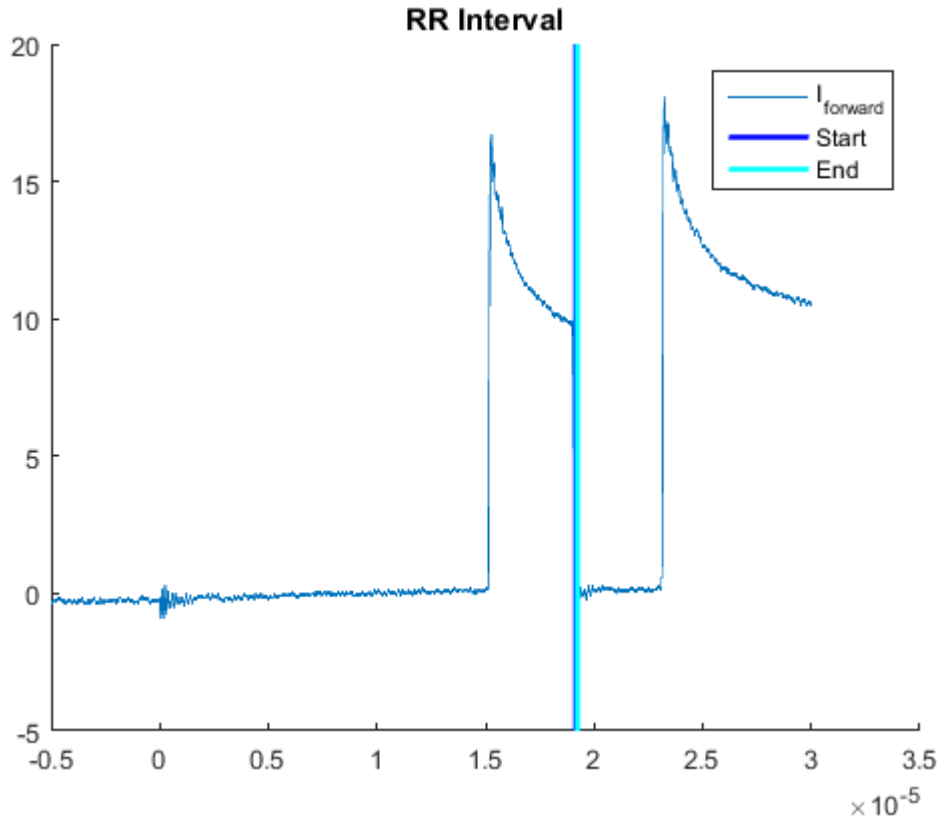
- Robust search algorithm for switching intervals



Reverse Recovery Interval

Define search window

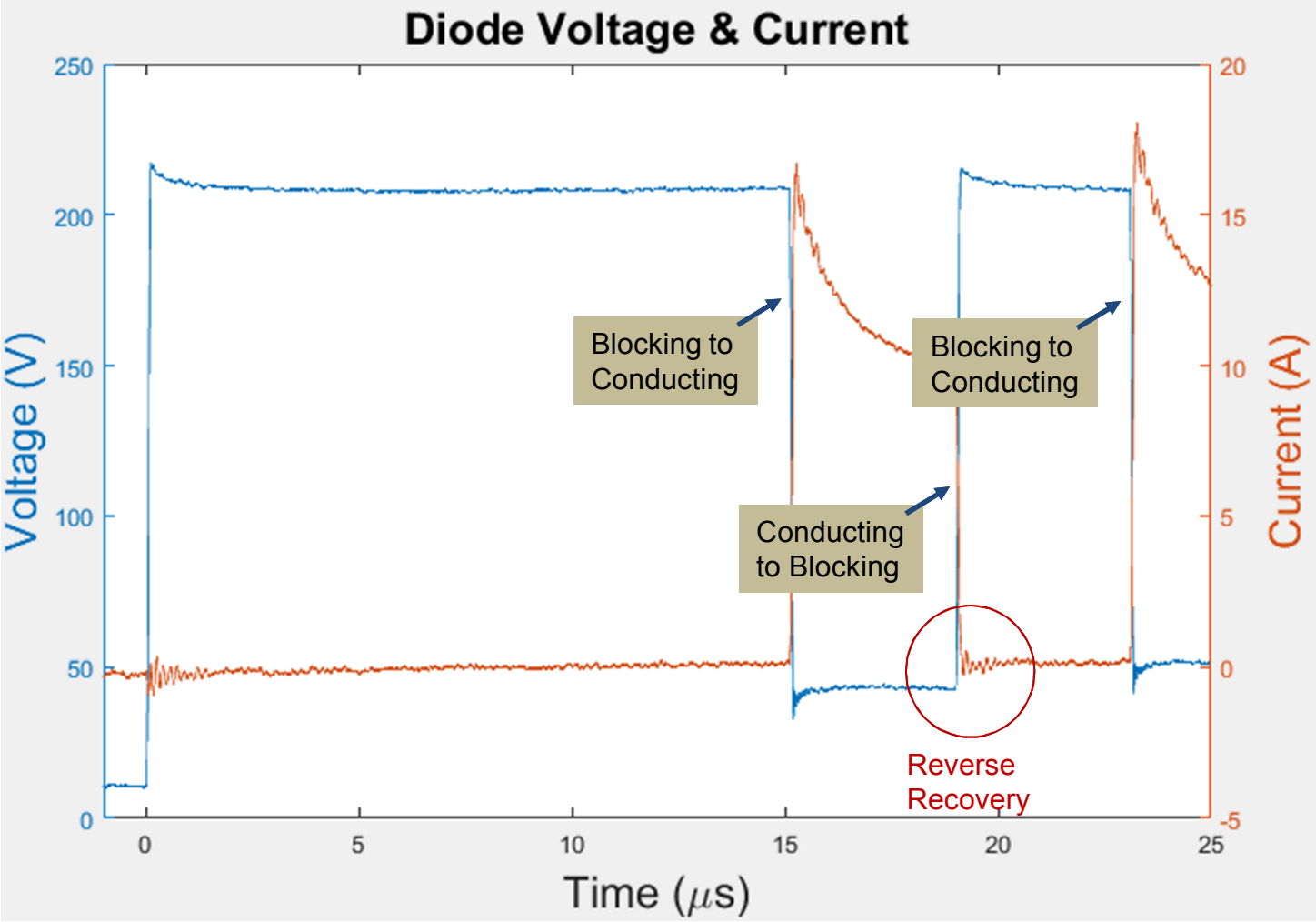
Define low level/Find start



Find minimum

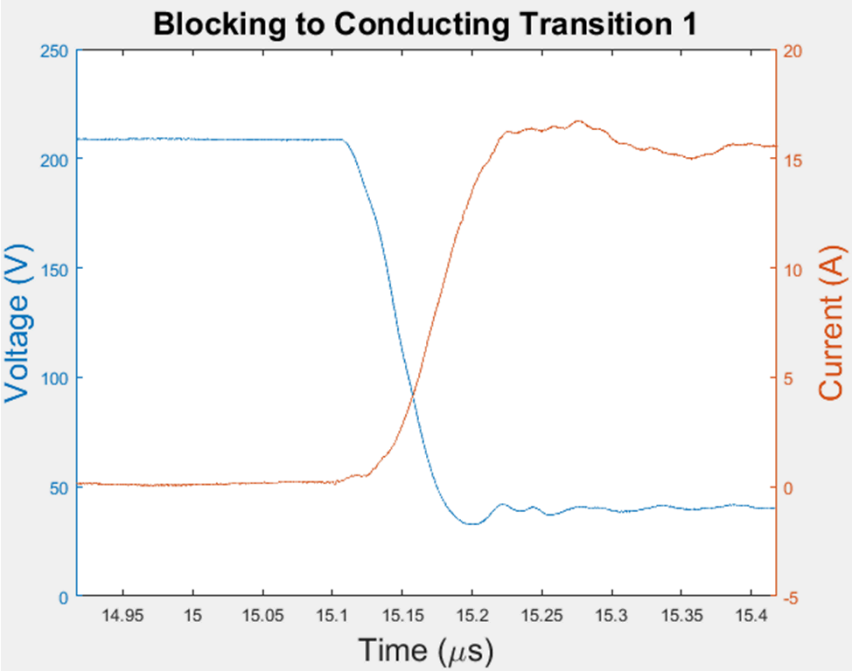
Find endpoint

Diode Switching

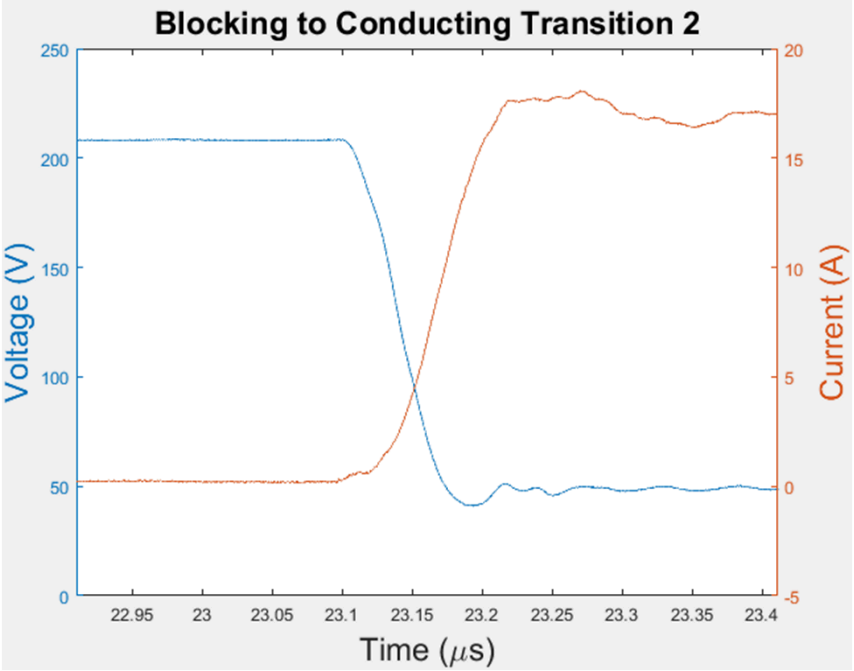


Blocking to Conducting

First Interval: 101.8 ns



Second Interval: 101.2 ns

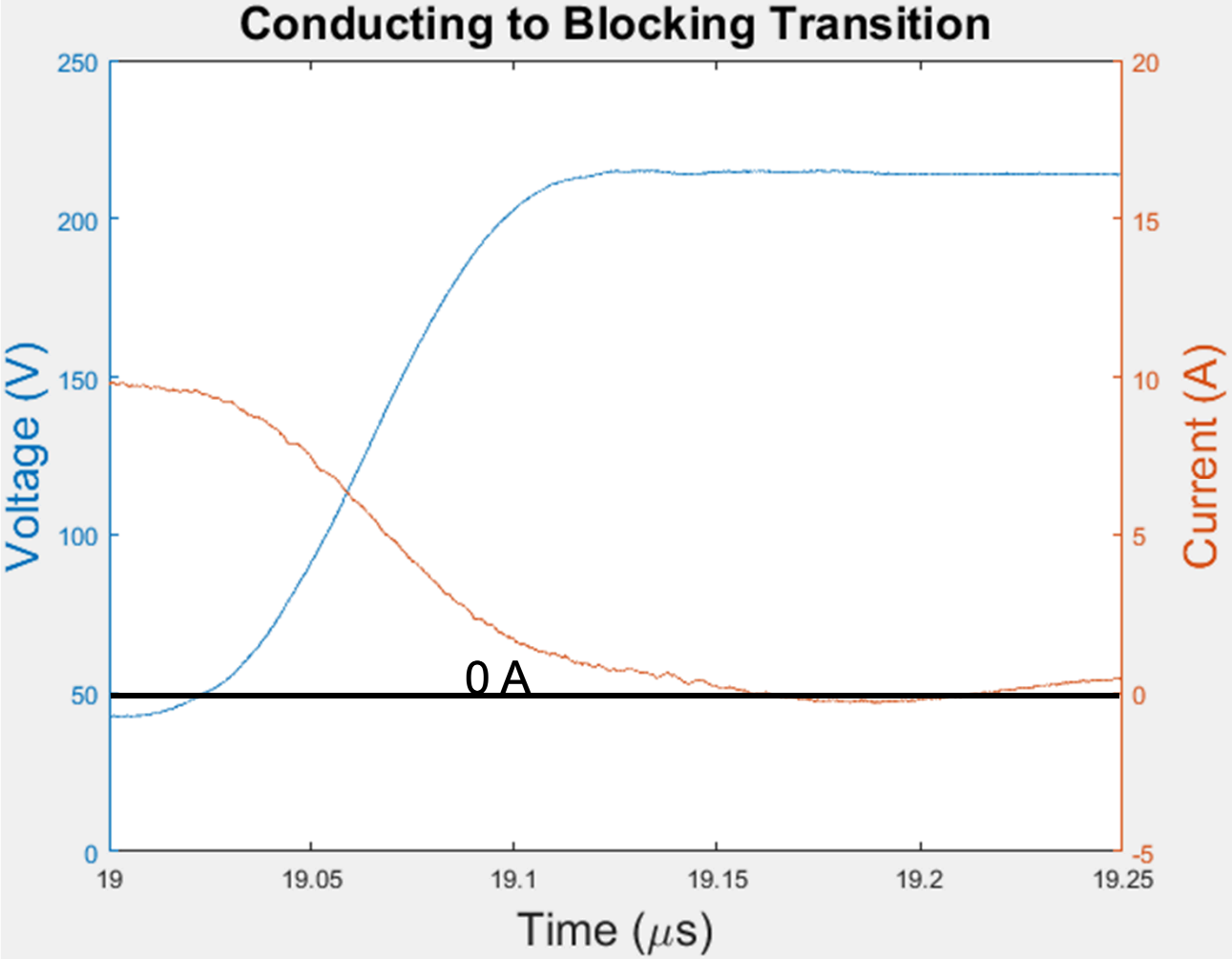


Avogy reports switching times on the order of 10 ns

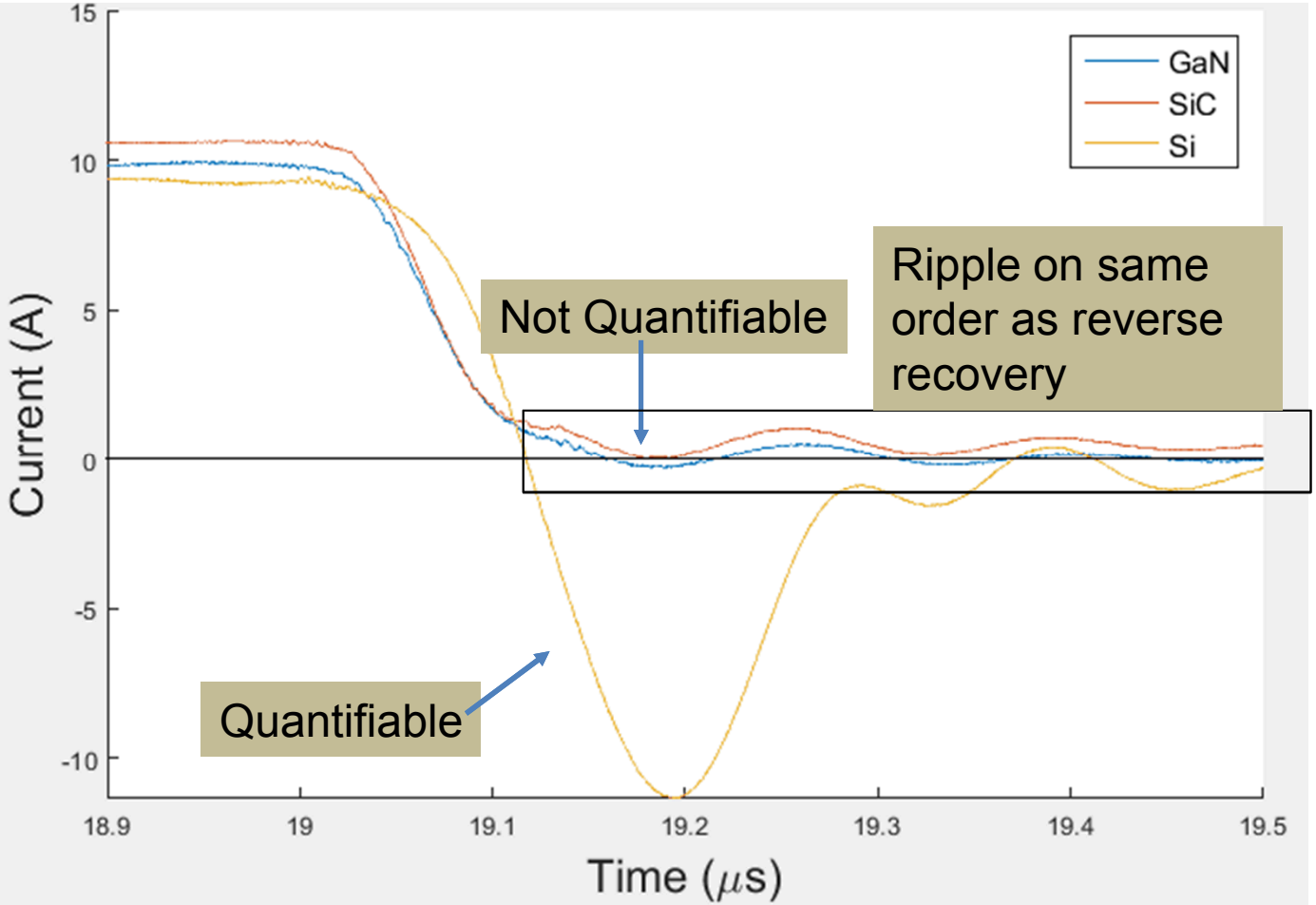
Kizilyalli et al., 2013

RC time constants dictate switching

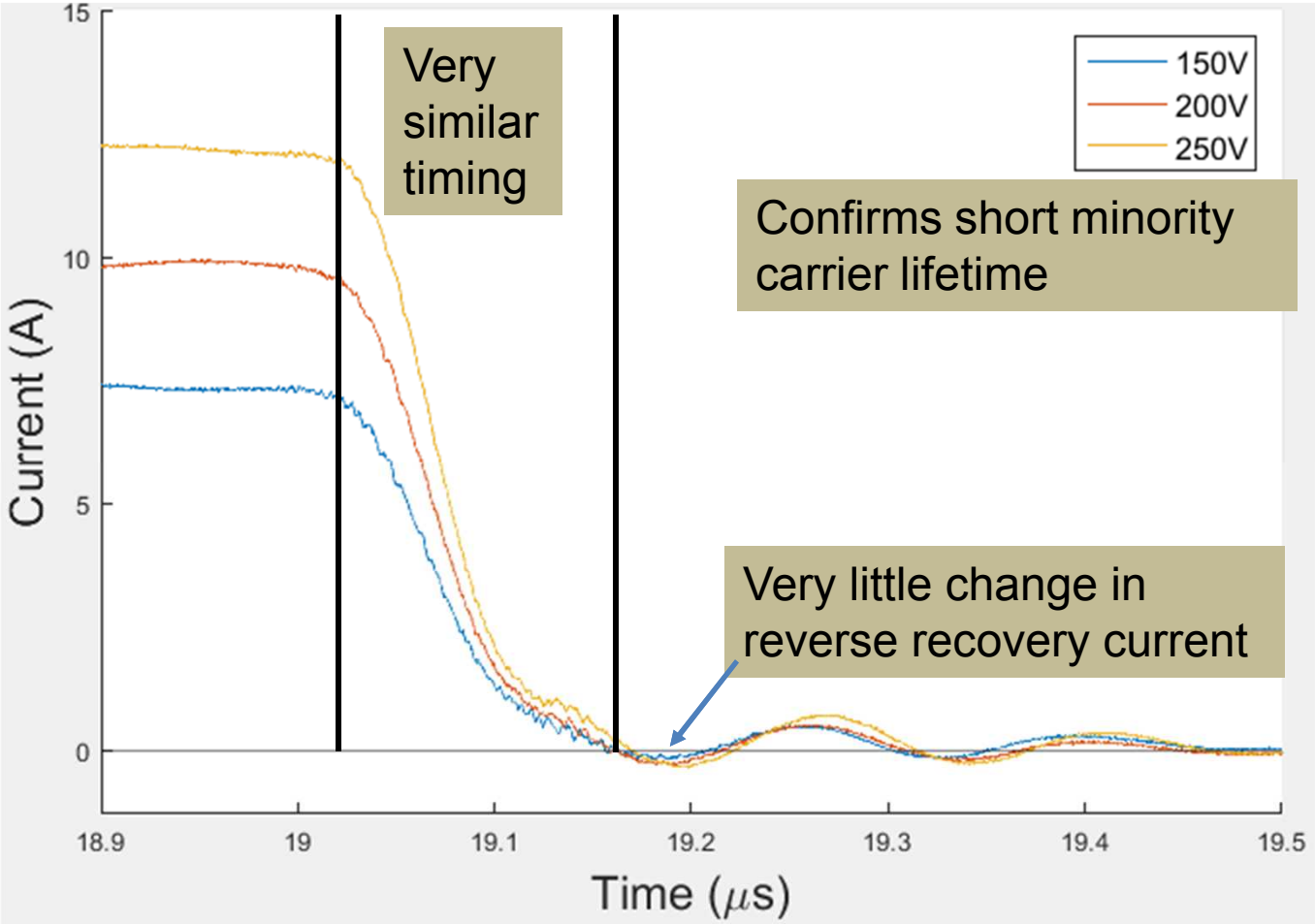
Conducting to Blocking



Material Comparison



Effect of Voltage



Conclusions

- v-GaN diodes are comparable to SiC SBDs in terms of switching, but can have higher breakdown
- Potential for fast & low-loss switching in power converters
- Recovery time limited by RC time constant, not minority carrier lifetimes

Future Work

- Optimize test circuit
- Conduct higher voltage testing
- Conduct reliability testing in

Acknowledgements

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QUESTIONS?