# Using TCAD to understand GaN design dependencies for Electric Vehicle applications

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**Bodo's Wide Bandgap Event 2024**

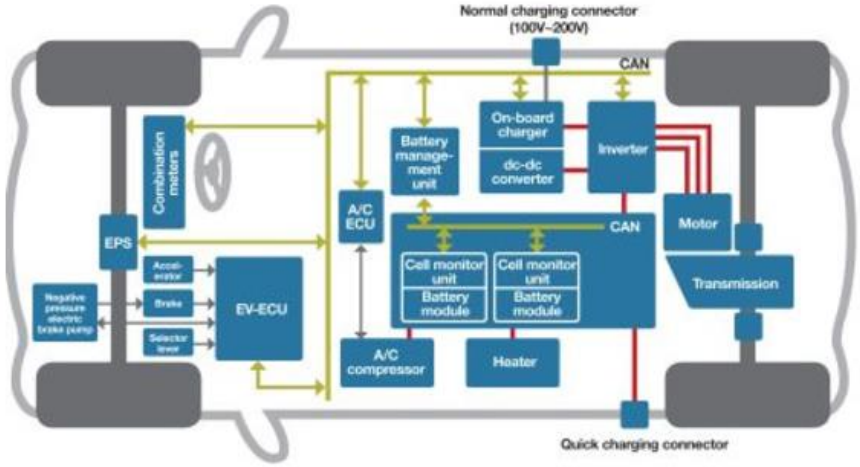
*Making WBG Designs Happen*

**GaN**

# Agenda Topics

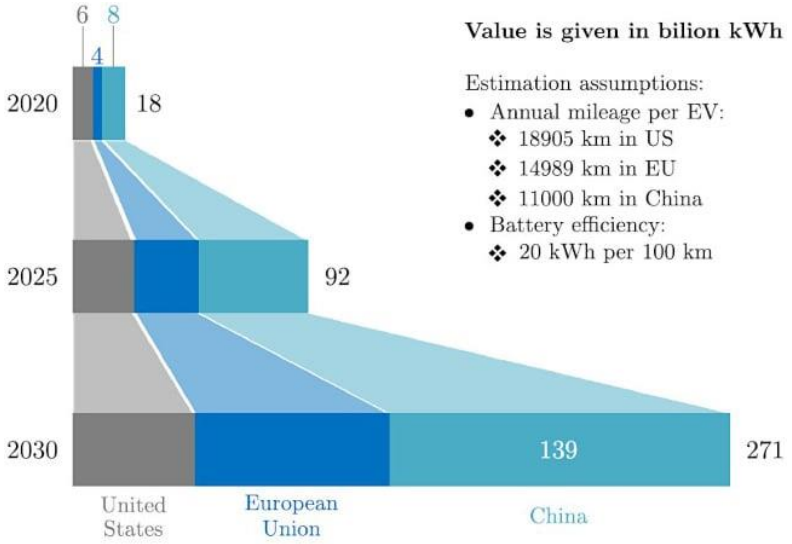
- Electric Vehicle trends and performance challenges
- TCAD for GaN design : How it is used today
- Extending TCAD : Introducing FTCO™

Typical EV Architecture




*Source : PowerElectronics Tips*

Global Trends on EV Use




*Source : Spectrum Logic*

# The EV Problem to be Solved

- Market demand has slowed : Pressure is on EV Manufacturers on Cost, Quality and Usability
- GaN can play a vital role in optimizing EV Performance

| Car | Battery (kWh) | Range (km) | Performance (km/kWh) | Cost per mile |
|---|---|---|---|---|
| Tesla Model 3 | 57.5 | 416 | 7.23 | 6.18p |
| Hyundai Ioniq | 77.4 | 488 | 6.59 | 6.80p |
| Vauxhall Corsa | 51.0 | 312 | 6.48 | 6.92 |
| Dacia Spring | 26.8 | 160 | 6.40 | 7.00 |
| Fiat 500e | 24.0 | 136 | 6.36 | 7.03 |
| BMW i4 eDrive40 | 83.9 | 512 | 6.35 | 7.06 |
| Peugeot e-208 | 51.0 | 304 | 6.32 | 7.08 |
| Mini Cooper E | 37.0 | 232 | 6.27 | 7.14 |

*Source : cargurus.co.uk 2024*

*Tesla Model 3*

*Dacia Spring Electric 45*

*BMW i4 eDrive 40*

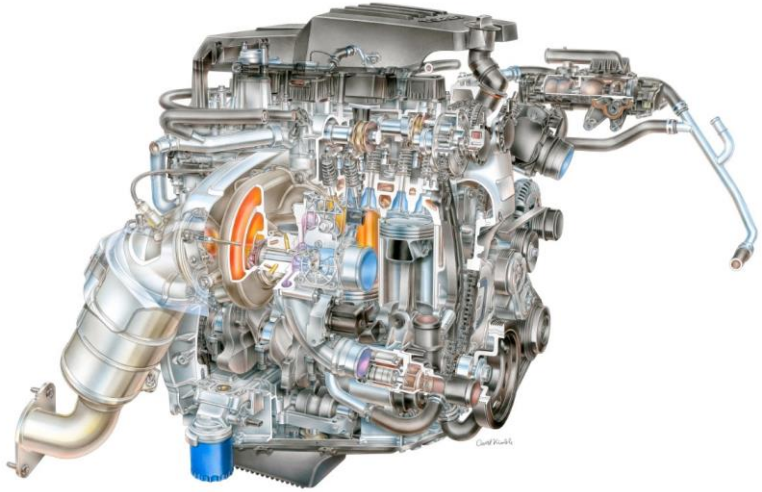
# Optimizing  for Efficiency

- Our generation has been extravagant with energy resources…
- Environmental arguments,  and tax incentives encourage all us to buy Electric Vehicles
- But there is market anxiety : Range, Infrastructure, Depreciation, ReCycling
- GaN based power converters can give is a further few % points of energy efficiency

| | Si | GaAs | 4H-SiC | GaN |
|---|---|---|---|---|
| Bandgap (eV) | 1.12 | 1.43 | 3.26 | **3.4** |
| Breakdown field ($10^6$ V/cm) | 0.3 | 0.3 | 2.5 | **3.0** |
| Thermal conductivity (W/cm/K) | 1.5 | 0.5 | 4.5 | **1.5** |
| Saturated velocity ($10^7$ cm/sec) | 1.0 | 1.0 | 2.0 | **1.5** |
| Electron mobility ($cm^2$/V/sec) | 400 | 4000 | 500 | **1800** |
| Hole mobility ($cm^2$/V/sec) | 480 | 400 | 110 | **150** |
| Dielectric constant | 11.9 | 13.1 | 10 | **10.4** |

**Energy Efficiency:**

- **Internal Combustion : 20-30%**
- **Electric Vehicle  : 75-80%**



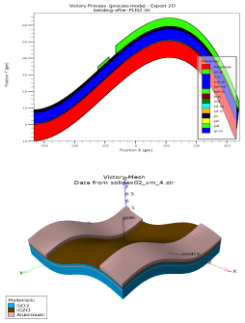
*Source JD Power*

# TCAD is an essential starting point for GaN design

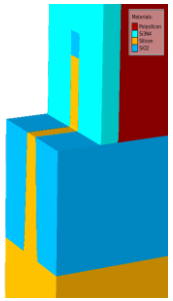
- TCAD allows designers to investigate design options, and predict device behavior

## Modeling Semiconductor Fabrication

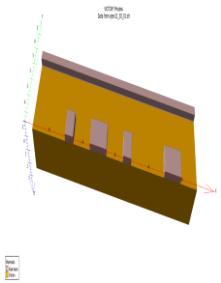
Oxidation



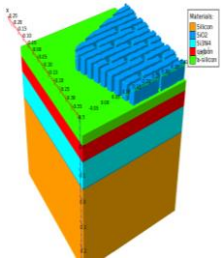
Stress/Strain



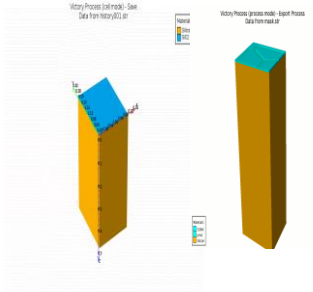
Epitaxy



CMP

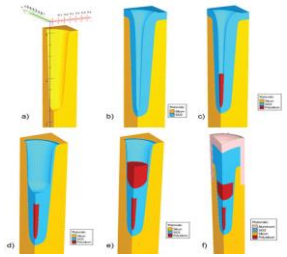


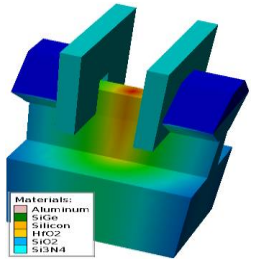
Patterning

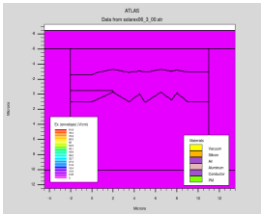


Etch/Dep

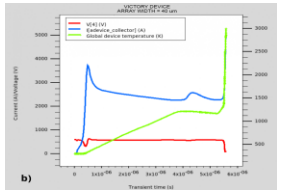
## Simulating Semiconductor Behavior



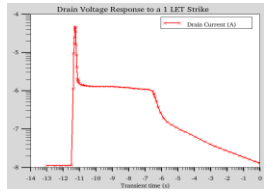


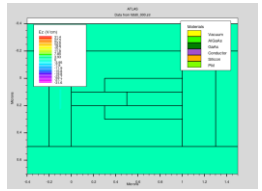
Power



Radiation



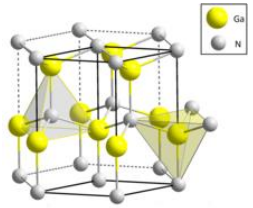

Optical

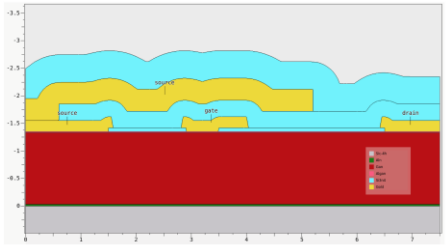


# GaN : Multiple Design Variables

## Designers can investigate dependencies and improve understanding using TCAD

- Geometry
- Contacts
- Shields
- GaN Buffer
- Doping
- Molar Concentration
- Impurities

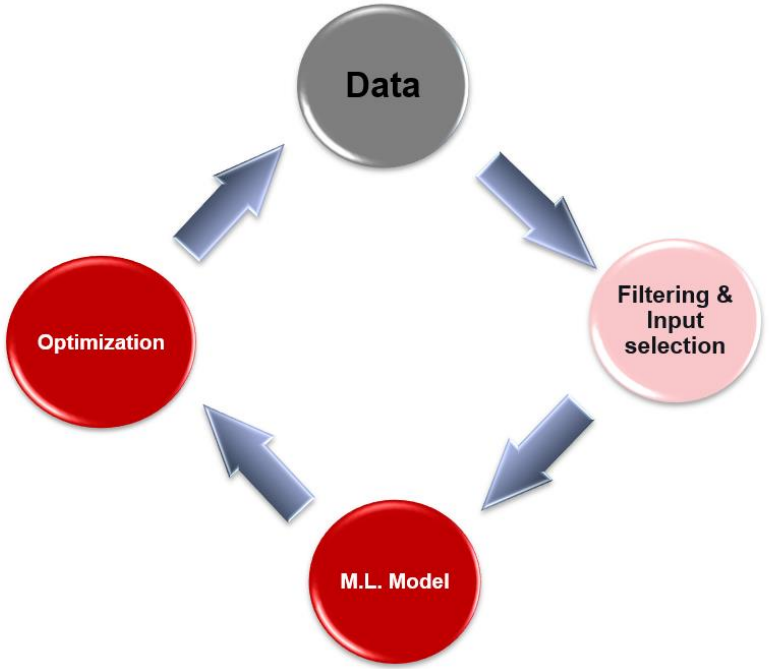



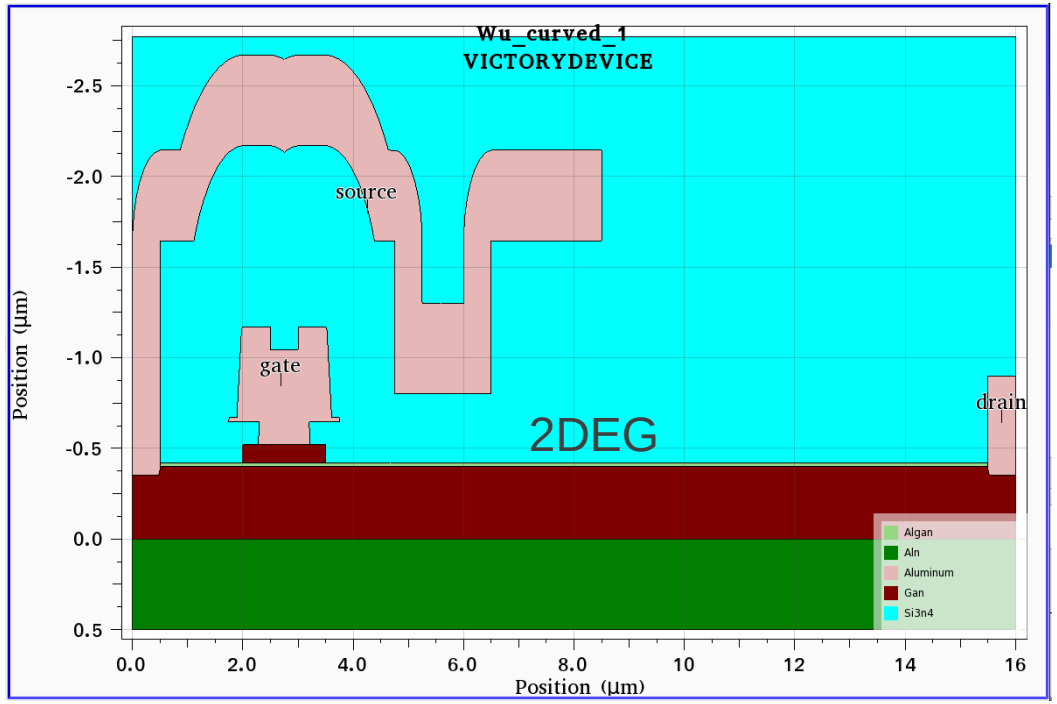


- RDS On
- Thermal Conductivity
- Gate Capacitance
- Charge Density
- Blocking Voltage
- Parasitics
- Transient Switching

# Extending TCAD with Design of Experiments (DOE)

- Test Example : Lateral AlGaN/GaN HEMT
  - Optimize BV and RDSON
- Use DOE to identify the variables with high influence
- Use ML to analyze the data and match the simulation to the actual device




"Breakdown voltage improvement of enhancement mode AlGaN/GaN HEMT by a novel step-etched GaN buffer structure" Hao Wu, Xiaojun Fu, Yuan Wang, Jingwei Guo, Jingyu Shen, Shengdong Hu# https://doi.org/10.1016/j.rinp.2021.104768

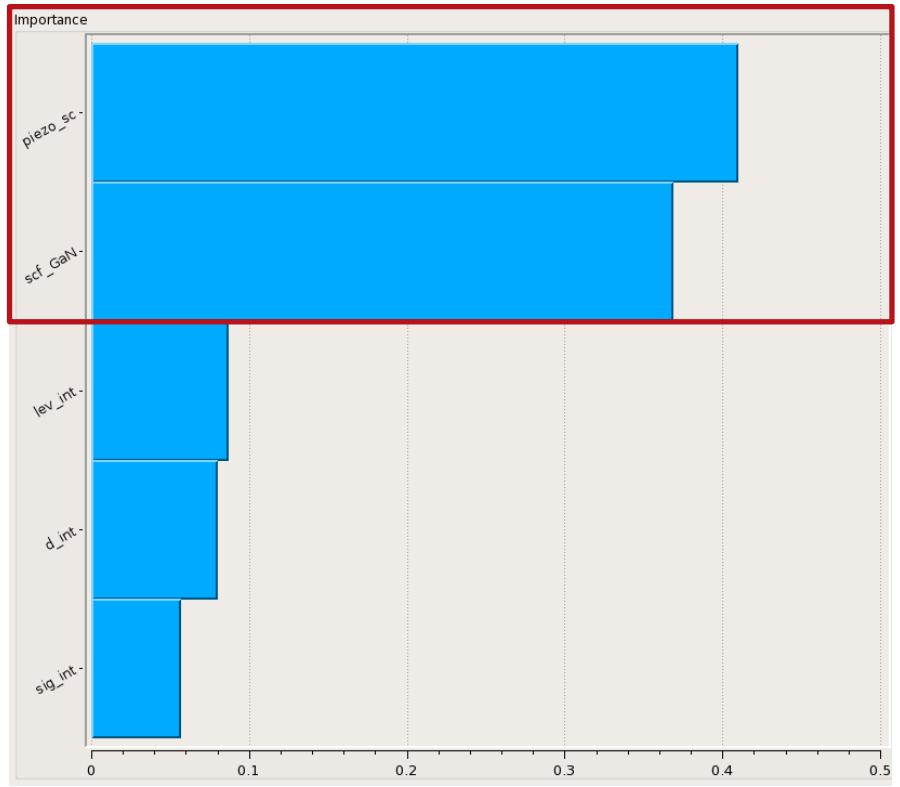
# GaN Parameter Analysis

## Experiment with the GaN Design Variables

- A collection of simulation results is assembled, with analysis of the most critical variables

| | Init | Low | High |
|---|---|---|---|
| scf_GaN | 0.6 | 0.36 | 0.84 |
| scf_AlGaN | 2.1 | 1.26 | 2.94 |
| piezo_sc | 0.65 | 0.39 | 0.91 |
| lev_acc | 2.85 | 1.71 | 3.99 |
| d_acc | 1.000e+17 | 6e+16 | 1.4e+17 |
| sig_acc | 1.000e-15 | 6e-16 | 1.4e-15 |
| lev_don | 0.5 | 0.3 | 0.7 |
| d_don | 2.000e+17 | 1.2e+17 | 2.8e+17 |
| sig_don | 1.000e-15 | 6e-16 | 1.4e-15 |
| lev_Mg | 0.16 | 0.096 | 0.224 |
| d_Mg | 3.000e+18 | 1.8e+18 | 4.2e+18 |
| sig_Mg | 1.000e-13 | 6e-14 | 1.4e-13 |
| d_int | 1.500e+19 | 9e+18 | 2.1e+19 |
| lev_int | 0.3 | 0.18 | 0.42 |
| sig_int | 5.000e-14 | 3e-14 | 7e-14 |

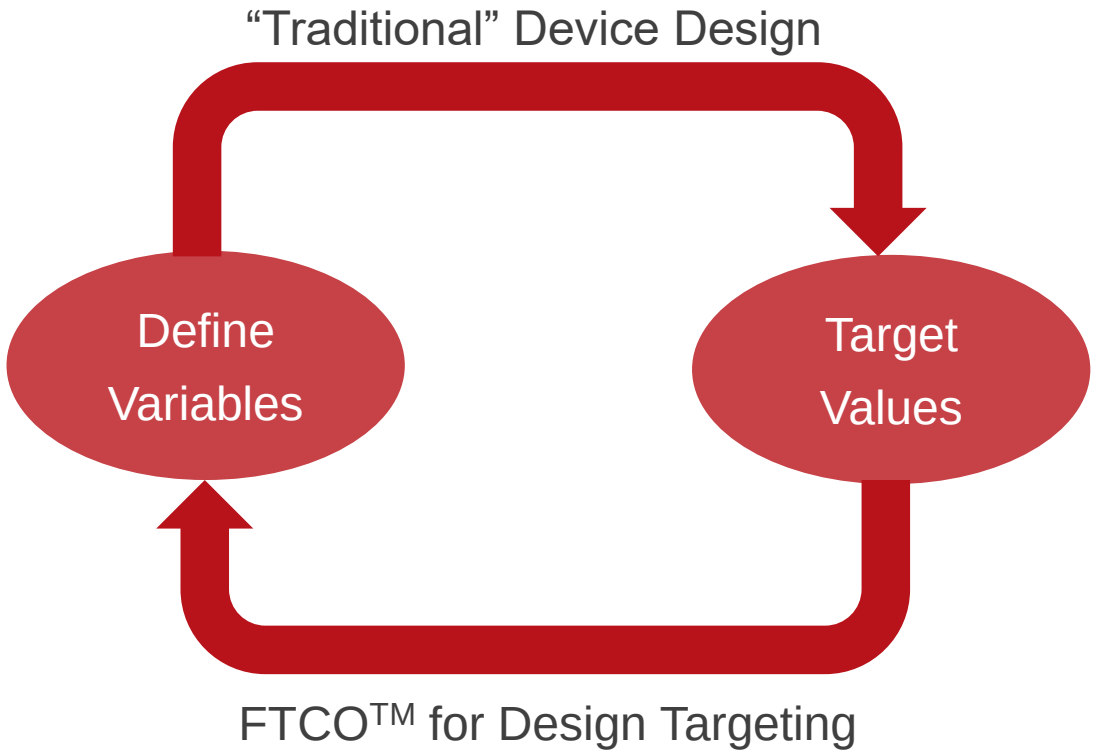
Filter



# Extend the process to include Manufacturing : FTCO™

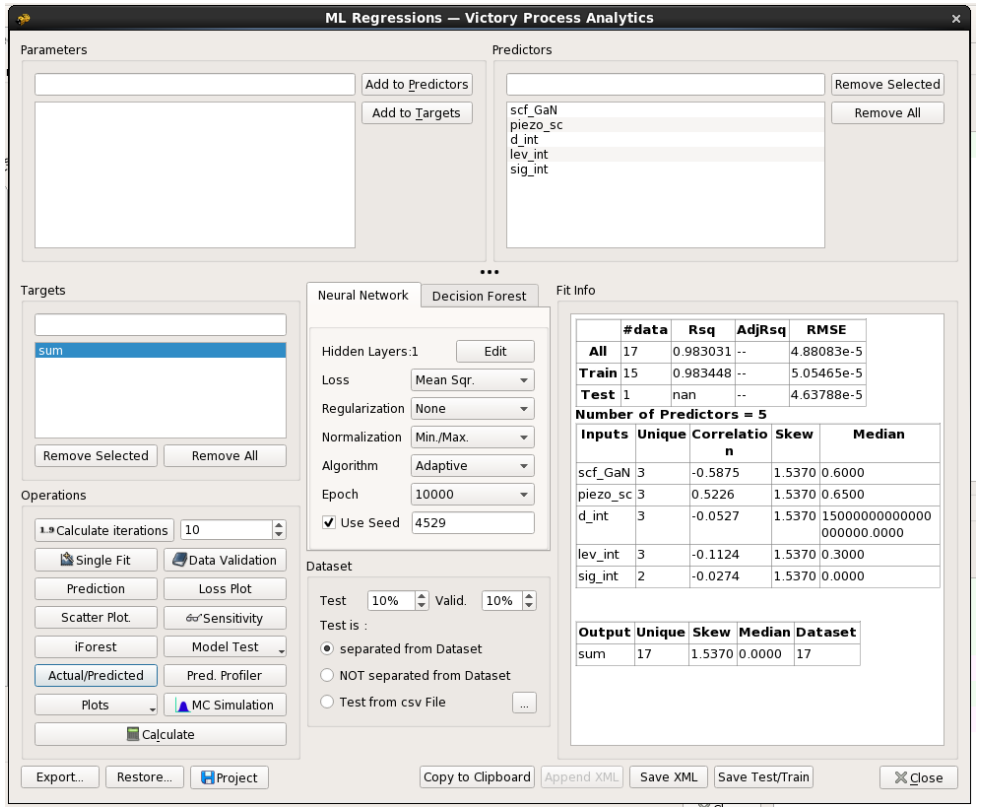
## Gain deep manufacturing variables and improve quality and yield

- Design Targeting:
  - Provide design targets, define design inputs
  - “Digital Twin” model returns input values to achieve the targets
- More **efficient**, more **precise** specification
- Determines **dominant inputs** to rapidly understand and optimize technology
- What does the designer  really need to worry about?

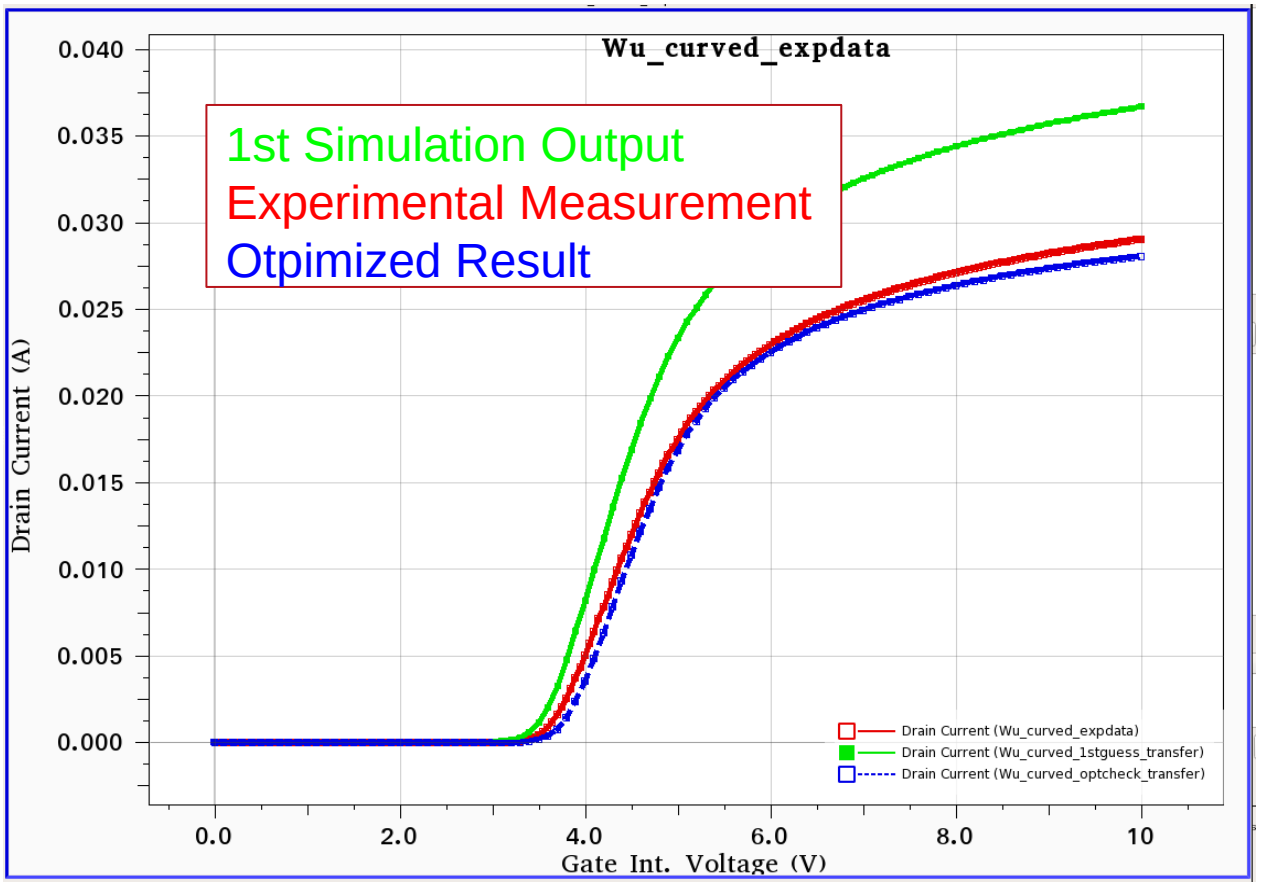


# Machine Learning algorithm generates  Digital Twin

## Digital Twin can be used by Fab engineers to improve yield and quality

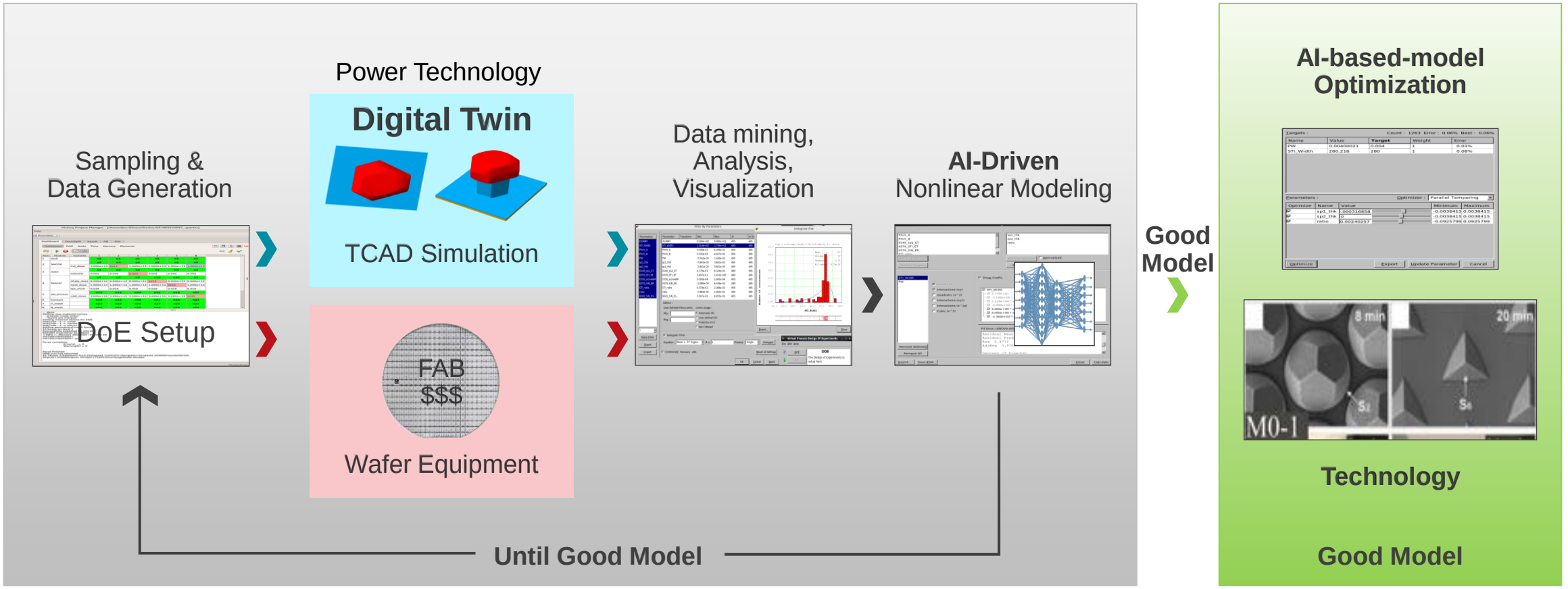



Victory Analytics Machine Learning




Optimized Digital Twin

# FTCO™ : Amalgamated TCAD, Fab and Digital Twin Data




- Measurement data from fab-out wafers (electrical)
- Measurement data from in-line metrology (structural)
- Device Modeling (TCAD, SPICE) – Target Optimization
- Reduce cost of manufacturing / improve time to market
- Fewer wafer runs, failed trials
- More productive use of TCAD

# AESIN : Automotive Innovation with Power Electronics (UK)

## Supplier Collaboration for Automotive EV

- Compound Semiconductor Research
- Innovative Inverter Designs, Higher Switching Speeds
- Thermal Modelling and Packaging
- High Frequency performance, smaller magnetics, EMF
- Failure Modes, Short-Circuits, Aging Models
- Power Train Design
- EV ECUs (OBC, Traction Drive Controllers, SDV Controls)

https://aesin.org.uk/

# Summary

## Silvaco FTCO™ – Optimizing Power Semiconductor Devices

- WBG Materials such as GaN are complex to analyze
- Simulation data from TCAD together with harvested Manufacturing data can now be included in the design process ( FTCO™ )
- Improved GaN devices mean more efficient EV energy conversion
- GaN-based inverters are already being adopted for OBC, BMS applications in EVs

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Thank you.
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# Abstract

Optimizing the use of the available energy-budget in Electric Vehicle design has become a top objective for vehicle manufacturers, and their requirements ripple down the automotive supply chain.

The Benefits of GaN switching devices in automotive power applications are well documented, but how far can these devices be further adapted and improved to win wider adoption in automotive applications?

This presentation will look at the demands of the automotive industry, and the role of TCAD (Technology Computer Aided Design), and FTCO (Fab Technology Co-Optimization) tools in the GaN device design process.

By combining manufacturing data, actual device measurements, and simulation results into the design flow, engineers can maximize GaN device quality and performance.

Compromise on design parameters is application-specific