The global **Electrification of Everything** transformation is underway.

Pakal Customer Introduction

Introducing the IGTO(t)

First New Power Semiconductor in 45 years.

An extremely rare and useful achievement.

Direct Drop-In* Upgrade for *every* IGBT (and beyond) from 650 V up to >2500 V

In Simple Cost–Effective Silicon.

*Same drivers/controllers and switching mechanism.

Pakal Technologies, Inc.

- ***Formed 2017***
- ***ISO Certified***
- ***NextGen Silicon Fabless Power Semiconductor Designer***
- ***37 Issued Patents***
- ***7 Locations:*** San Francisco, Hsinchu, Hillsboro, Sendai, Berlin, Seattle, Silicon Valley
- ***Pakal Gen 2 – Sales NOW***

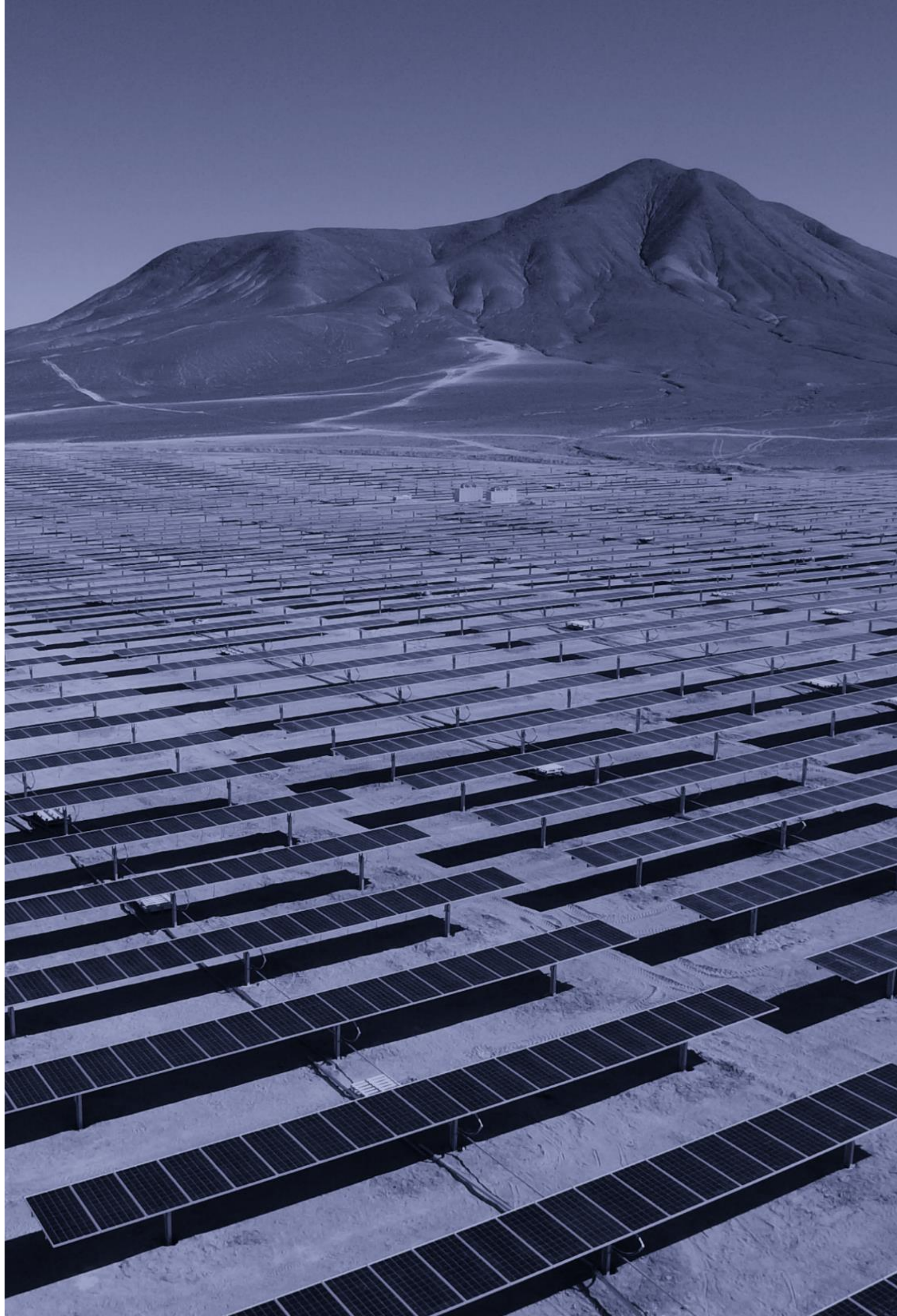
World Class Leadership

Team leverages the superior IGTO(t) platform

Dr Richard Blanchard & Dr Vladimir Rodov lead the team. Collectively, they and team have invented & commercialized:

- **Trench MOSFETS, $7B** annual global coverage
- SBR Diode, >$300 M annual, marketed by Diodes Inc
- FERD Diode, >$350 M annual, marketed by STMicro

Each example = **novel physics** in simple silicon!



Patented, Proven Silicon,
Pakal's IGTO(t)

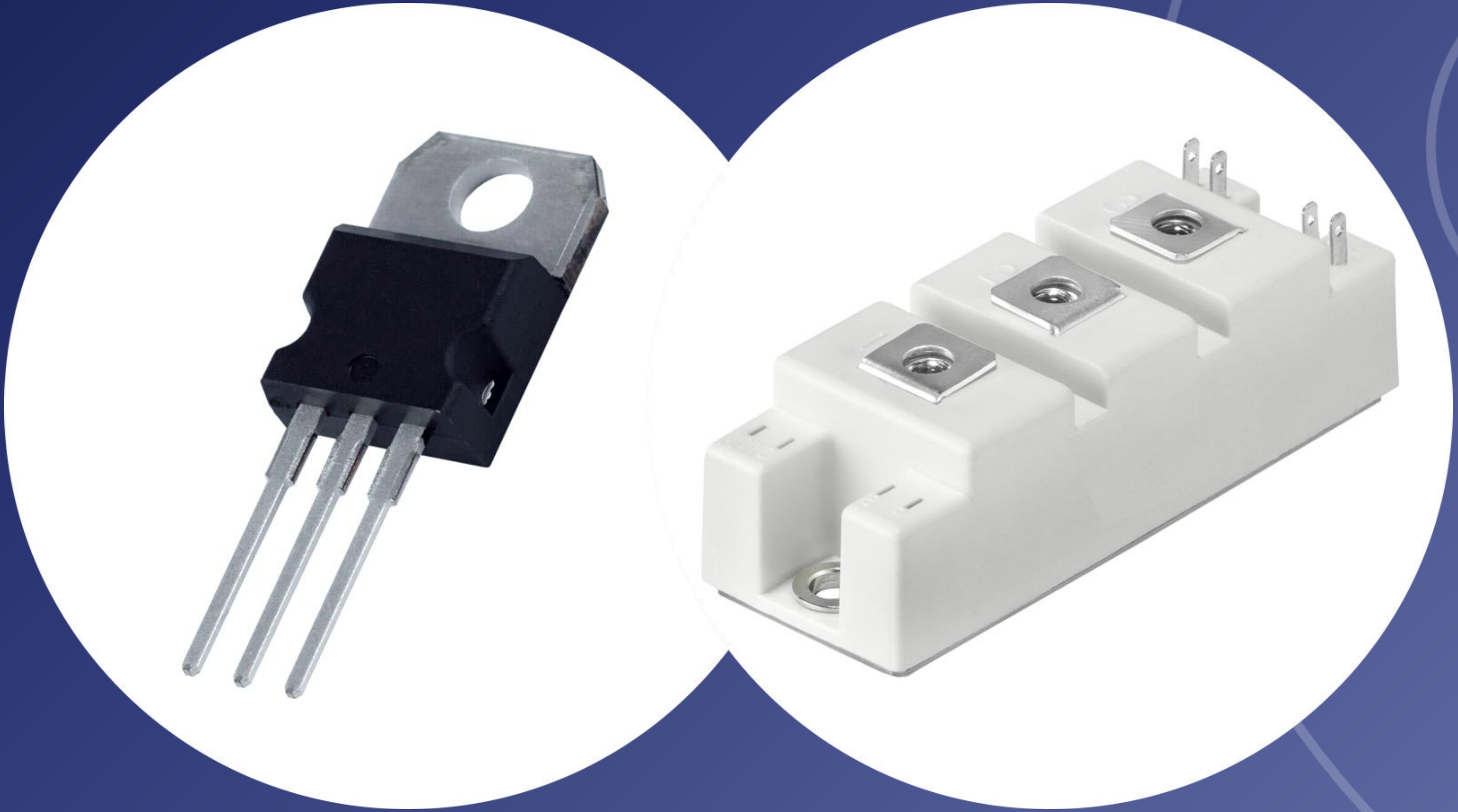
The IGTO(t) is a novel high-voltage (>600 V) **silicon** power semiconductor.

The IGTO(t) is a superior **direct drop-in replacement** for today's IGBT.

Same drivers and controllers, same voltage gate driven switching.

Silicon pricing with significant **efficiency gains.**

Anywhere the IGBT Goes, the IGTO(t) Will Go



Power Semiconductors: key enabler for Power Systems

Critical for ***every climate application*** especially green energy chain

Renewable energy generation

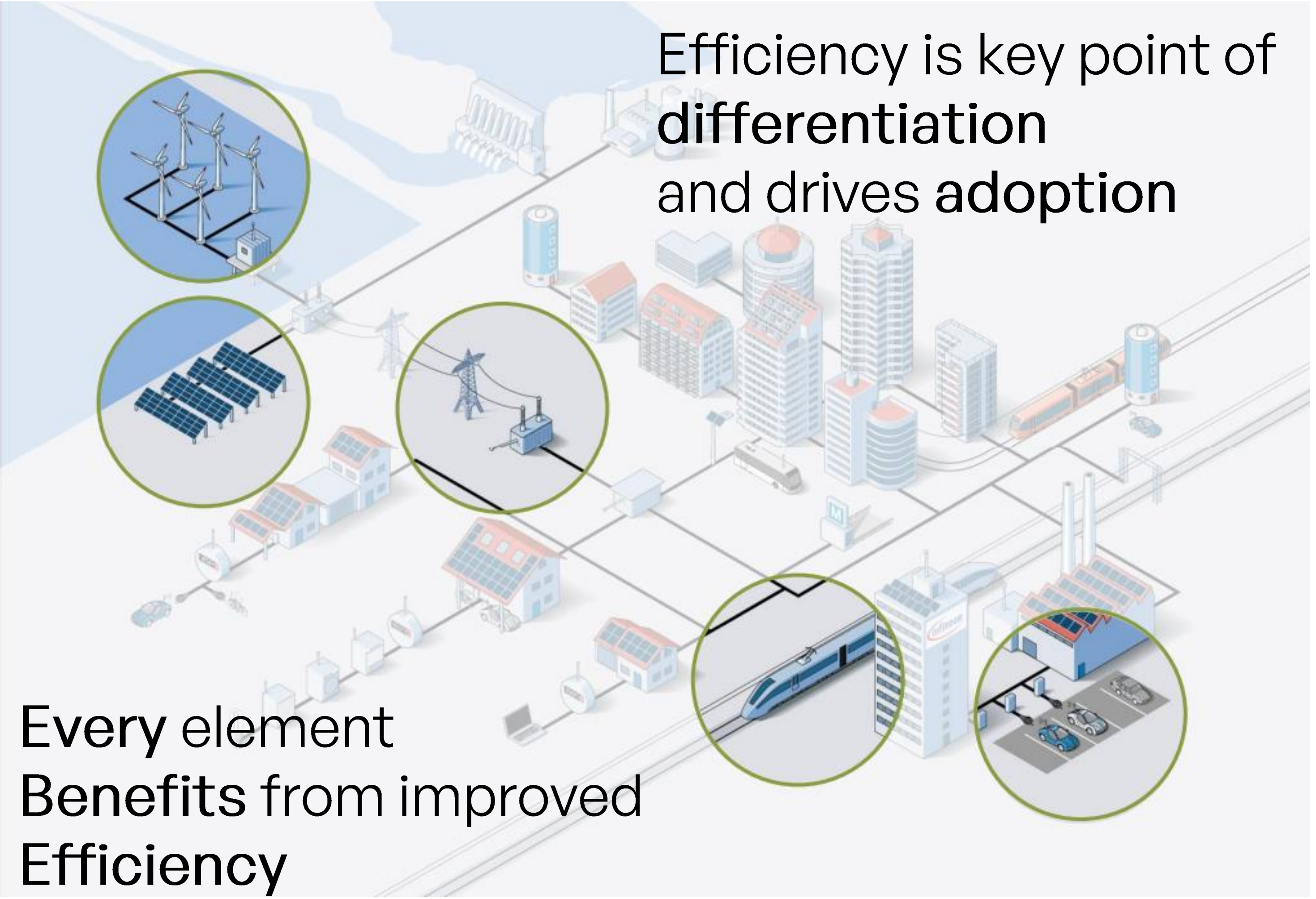
Wind, Solar and Hydro
Power Generation

Energy infrastructure

Grid network, storage and
EV Charging

Energy conversion and usage

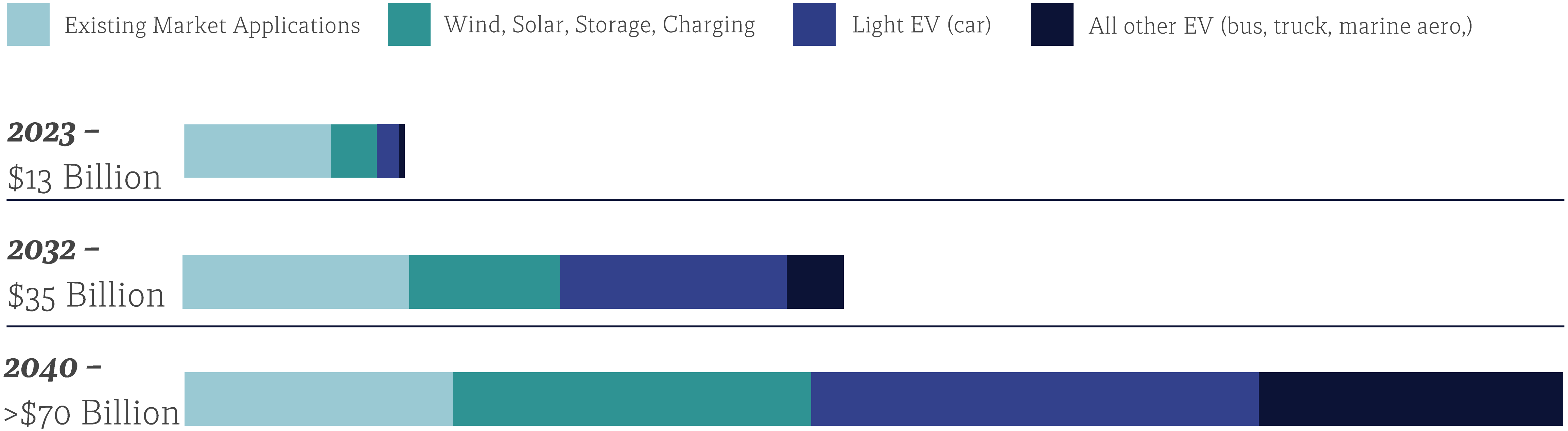
Vehicle Electrification,
Heat pump, Data Center,
Industrial power, etc, etc



Efficiency is key point of **differentiation**
and drives **adoption**

Every element
Benefits from improved
Efficiency

Globe Will Rapidly “Electrify Everything:”
20-year >600 V Power Semi Demand Growth.
Price and Scalability Matter.



AI and Grid Upgrade power conversion requirements add to this demand story!

Pakal Gen 2 650 V vs leading competitor Gen 5
Drop in Upgrade for Highspeed Gen 5

Value Prop:

In real-world operating temperature of 100 °C,

Very similar Ets, with **dramatic Vce(sat) reduction.***

	20 A		40 A	
@100°C	VCE(sat)	Ets	VCE(sat)	Ets
Competition Gen 5	1.50	0.66	1.92	2.19
Pakal Gen 2	1.17	0.67	1.42	2.22
Pakal Efficiency Gains	**0.33 V** **22%**	-	**0.50 V** **26%**	-

* Measured results, TO-247 Package, 20 Ohm Rg.

Pakal Gen 2 also Drop in Upgrade vs Gen 7 IGBTs

Value Prop:

In real-world operating temperature of 100 °C,

Lower Ets AND lower Vce(sat) = **>10% total efficiency gain.**

	20 A		40 A	
@100°C	VCE(sat)	Ets	VCE(sat)	Ets
Competition Gen 7	1.30	0.78	1.62	2.45
Pakal Gen 2	1.17	0.67	1.42	2.22
Pakal Efficiency Gains	**0.13 V 10%**	**0.11 mj 14%**	**0.50 V 12%**	**0.23 mj 9%**

IGTO(t) Product Release Schedule

Gen 2 650 V	**30** Amp TO-247 Co-pack or Discrete	**Orders Now**
Gen 2 650 V	**40** Amp TO-247 Co-pack or Discrete	**Orders Now**
Gen 2 650 V	**75** Amp TO-247 Co-pack or Discrete	**February ‘25**
Gen 2 1200 V	**30** Amp TO-247 Co-pack or Discrete	**January '25**
Gen 3 650 V	**200** Amp TO-247	**Beta Samples Feb '25**
Gen 3 1200 V	**100** Amp TO-247	**Beta Samples Feb '25**
Gen 2 1700 V	**25** Amp TO-247	**March '25**
Gen 2 650 V	**40** & **50** Amp D2-Pak	**April ‘25**

ZF Endorsement (>45 Billion Euro Revenue Automotive Supplier)

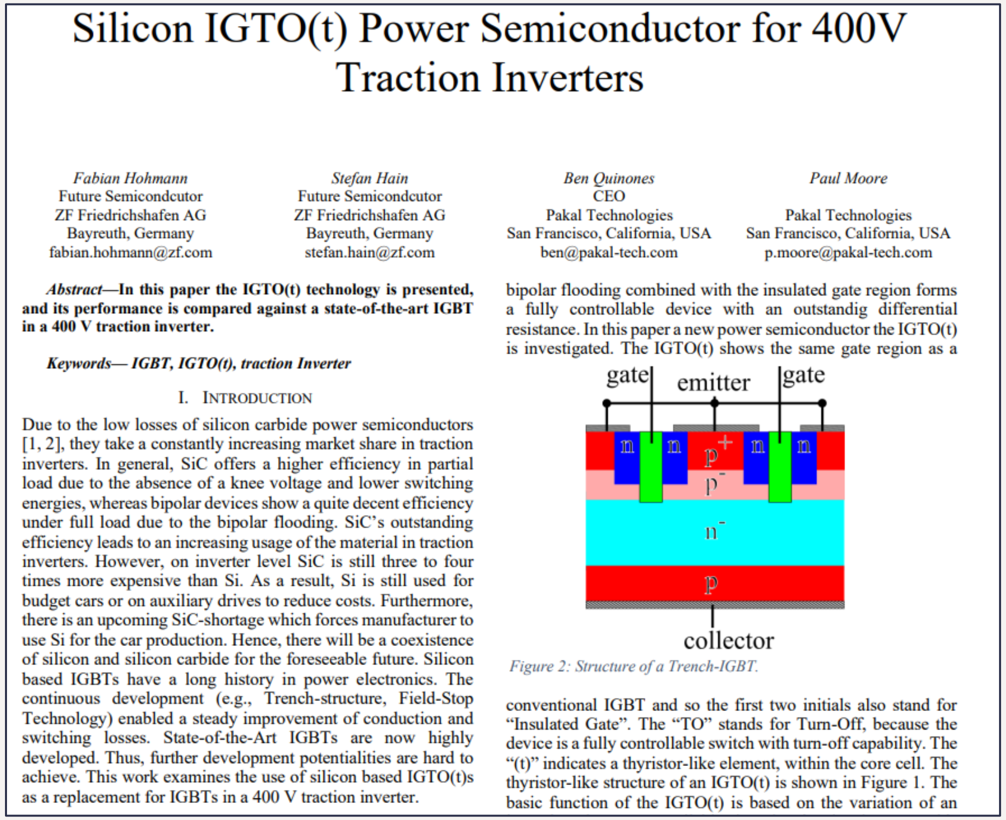
ZF IEEE white paper describes IGTO(t) Gen 2.0 benefits

“on inverter level, **SiC is still three to four times more** expensive than Si. . . .and there is an upcoming SiC shortage . . . **Hence there will be a coexistence of silicon and silicon** carbide for the foreseeable future.”

“**Trench-structure, Field-Stop** enabled a steady improvement of conduction and switching losses. . . . State-of-the-Art **IGBTs** are now **highly developed**. Thus, **further development** potentialities are **hard to achieve**.”

“in comparison with state-of-the-art IGBTs . . . **the possible loss reduction reaches from 11%** for the inverter with small output power **up to 19%** for the high-power inverter.”

Written by:
Dr Fabian Hohmann & Dr Stefan Hain
Future Semiconductor, ZF Friedrichshafen AG



Silicon IGTO(t) Power Semiconductor for 400V Traction Inverters

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***Abstract*—In this paper the IGTO(t) technology is presented, and its performance is compared against a state-of-the-art IGBT in a 400 V traction inverter.**

Keywords— IGBT, IGTO(t), traction Inverter

I. INTRODUCTION

Due to the low losses of silicon carbide power semiconductors [1, 2], they take a constantly increasing market share in traction inverters. In general, SiC offers a higher efficiency in partial load due to the absence of a knee voltage and lower switching energies, whereas bipolar devices show a quite decent efficiency under full load due to the bipolar flooding. SiC’s outstanding efficiency leads to an increasing usage of the material in traction inverters. However, on inverter level SiC is still three to four times more expensive than Si. As a result, Si is still used for budget cars or on auxiliary drives to reduce costs. Furthermore, there is an upcoming SiC-shortage which forces manufacturer to use Si for the car production. Hence, there will be a coexistence of silicon and silicon carbide for the foreseeable future. Silicon based IGBTs have a long history in power electronics. The continuous development (e.g., Trench-structure, Field-Stop Technology) enabled a steady improvement of conduction and switching losses. State-of-the-Art IGBTs are now highly developed. Thus, further development potentialities are hard to achieve. This work examines the use of silicon based IGTO(t)s as a replacement for IGBTs in a 400 V traction inverter.

bipolar flooding combined with the insulated gate region forms a fully controllable device with an outstandig differential resistance. In this paper a new power semiconductor the IGTO(t) is investigated. The IGTO(t) shows the same gate region as a conventional IGBT and so the first two initials also stand for “Insulated Gate”. The “TO” stands for Turn-Off, because the device is a fully controllable switch with turn-off capability. The “(t)” indicates a thyristor-like element, within the core cell. The thyristor-like structure of an IGTO(t) is shown in Figure 1. The basic function of the IGTO(t) is based on the variation of an

Figure 2: Structure of a Trench-IGBT.

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