Green Power Solutions

HVDC overview
High voltage semiconductors

Stefano Melzi – Sisram-Dynex

GPS Tech Seminar 2023

COMPANY OVERVIEW

Zhuzhou CRRC Times Semiconductor Co.,Ltd.

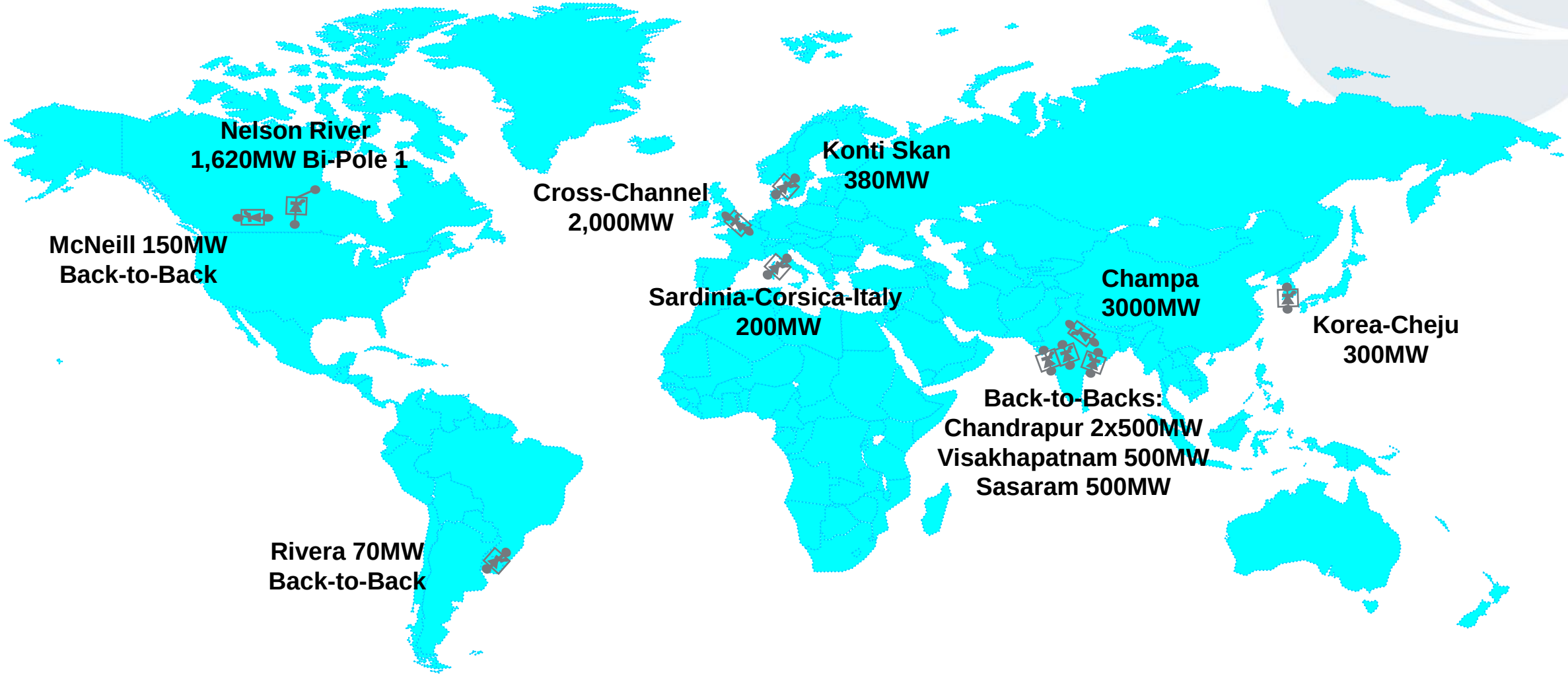
- Yixing CRRC Times Semiconductor Co., Ltd. (100%)
- Dynex Semiconductor (100%)
- Guangzhou Cyan Semiconductor Co., Ltd. (49%)
- Zhixin Semiconductor Co., Ltd. (47%)
- Hunan Coresing Semiconductor technology Co., Ltd. (25%)

- Bipolar Manufacturing Center
- Module Manufacturing Center
- Wafer Manufacturing Center
- Sales & Marketing Center
- R & D Center （Zhuzhou & Lincoln）

- Functional Department
- Fulfillment Center

Global production capability 2023 : 400,000 wafers
2024 : 700,000 wafers

Dynex Experience with HVDC



Power Grid in China

- Served 22 HVDC projects and 5 flexible HVDC projects to date
- HVDC thyristor takes up 50% of total market share in China
- IGBT takes up 20% of total market share in China

Application and Performance

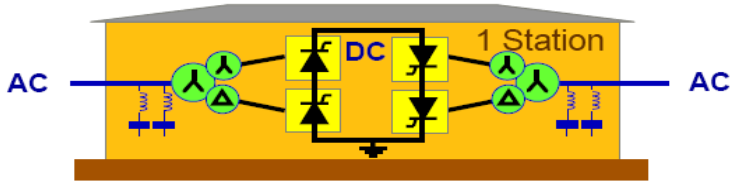
HVDC

- ✓ Thyristor
- ✓ Multiple device in series
- ✓ AC-DC,DC-AC
- ✓ High-voltage system, need multi-devices in series, e.g. ±500kV, ±800kV, ±1100kV
- ✓ Long-distance tansmission

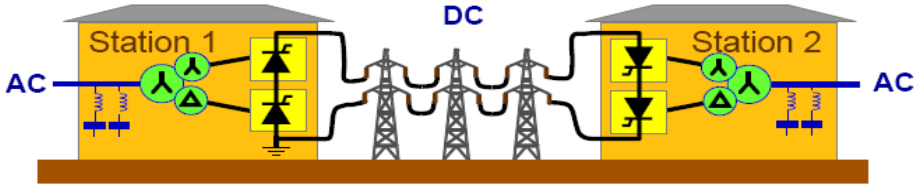
Symbol	Parameters Name	Unit	Requires
Ton	Turn-on time	us	±1
Qrr	Reverse Recovery Charge	Uc	±200
IGT	Gate Trigger Current	mA	±50
di/dt	On-state Current Critical Rising Rate	A/us	High di/dt demand

HVDC Scheme Types

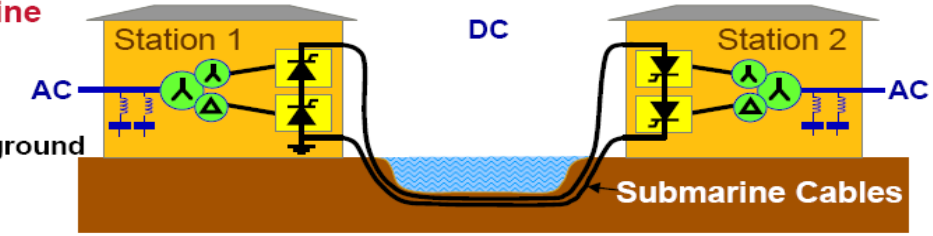
- **Back-to-Back**
  - frequency changing
  - asynchronous connection



- **Point-to-Point Overhead Line**
  - bulk transmission
  - overland



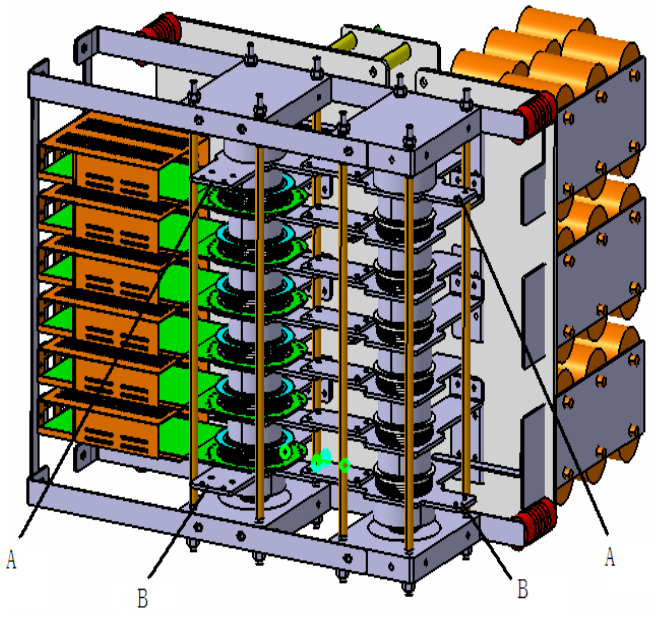
- **Point-to-Point Submarine Cable**
  - bulk transmission
  - underwater or underground



IGCT Application Reference

IGCT DC breaker application （CAc4000-45-02）

2015 - 10kV/3.5kA hybrid breaker for DC power networking



Bipolar for HVDC

HVDC Thyristor Redesign Project

Aim

- *“Redesign and development of optimised and robust range of 8.5kV HVDC thyristors at 100mm, 125mm and 150mm.”*

Key

- Have developed in house robustness test
  - “Cold-Clamped Transition Voltage” (CCTV)
  - Significantly more harsh than operational tests

Technical Changes

- New gate design
- New silicon
- New diffusion process
- New housing

HVDC Thyristor Redesign Project: Housing

Dynex standard

- Asymmetric housing

Redesigned package

- Symmetric
  - Anode & cathode pole pieces same thickness
  - Improved pressure distribution
  - Reduces stress on silicon
- Increased molybdenum diameter
  - Reduces stress on silicon
    - Particularly at edge
  - Common for all three device diameters

HVDC Thyristor Redesign Project: Devices

- **125mm - DCR3670H83-2565**
  - Dynex qualification complete
  - Awaiting customer sampling
- **100mm - DCR2500A83-2564**
  - Dynex qualification complete
  - Customer samples available
- **150mm - DCR4570K83-2566**
  - 2 gate designs
  - Production testing complete
  - Awaiting qualification - includes final decision on gate design

Bipolar Product

World Top 1 in HV Thyristors; Market share >40% in China

Bipolar Device

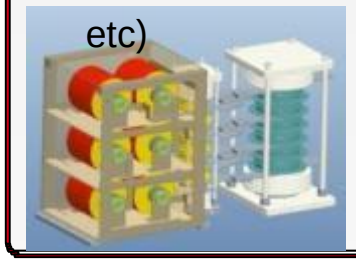
- 5 , 6 and 7inch HV thyristors/diodes based on free-floating technology;
- All devices pass rigorous verification and engineering application
- Full product range to meet customer requirement
- Heatsinks are avaliable according to customer need

Full Controlled Device

- Capable of designing and manufacturing 4~6 inches IGCT devices
- Max. controllable turn-off current more than 15kA
- FRD products are available according to customer design
- Multiple product selections, electrical and structural solutions can be provided according to customer need

Power Assembly

- Design and manufacturing capabilities of power assemblies upto 6inch devices;
- High voltage and high current test ability to meet different application requirement
- Different designs pass the application verification in different fields (HVDC , MV convertor, locomotive converter, etc)

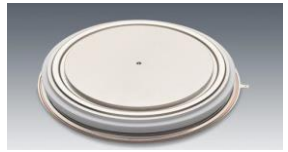


Bipolar Product

- **Short-term:** Improve the capability of bipolar device manufacturing process platform and enhance product competitive advantage
- **Medium-term:** Develop high-voltage, high-pass flow, high-shutdown IGCT products, and achieve market breakthroughs in power grid and industrial fields
- **Long-term:** Develop bipolar device 2.0 platform, support the upgrading of thyristors for smart grid

Thyristor

6500V Breakdown Thyristor



Bipolar Press-pack modules

High junction,high power Thyristor &FRD

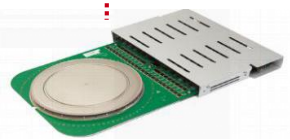
IGCT

4500V/6500A AS-IGCT

2022

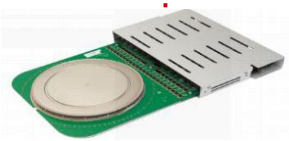
6500V/4000A RB-IGCT

2023



8500V/5000A RB-IGCT

2024



4500V/15000A AS- IGCT
6500V/8000A RB- IGCT

2025

Low loss
Higher junction/temperature
Higher switching Power **Bipolar 2.0 Platform**

IGCT - Product Development Milestones

GTO Production platform

2003-2007

Design & Manufacturing platform for CA_C 3000-45

R&D the Gate Unit

2005-2008

2008-2010

CAc 4000-45 IGCT
FY_9 900-45 FRD
FYx 1100-45 FRD

CAc 3000-60 IGCT
FYx 800-60 FRD
FY_B 1100-60 FRD

2010-2013

2013-2015

CRc 2200-45 IGCT

CAc 5000-45 IGCT
FY_B 2000-45 FRD
FY_X 2000-45 FRD

2015-2016

2016-2019

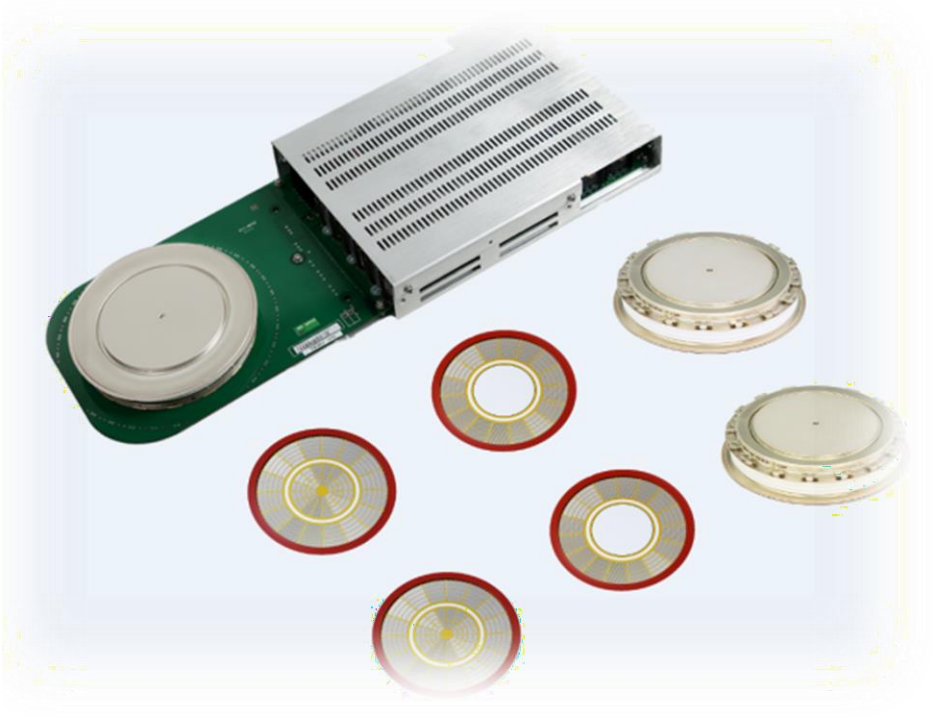
6-inch CA_E8000-45 IGCT

CS_E 500-45 RB_IGCT

2018

IGCT Products & Technology

IGCT products series



IGCT/GCT outline

Asymmetric Type	Package (mm)
CA_c 4000-45-01	85/26
CA_c 4000-45-02	85/26
CA_c 3000-60	85/26
CA_c 5000-45	85/26

Reversing Conducting Type	Package (mm)
CR_C 2200-45	85/26

*** Pole Diameter (D) /Case Height (H)**

FRD Products series

FRD TYPE (Free Floating)	Package (mm)
FY_9 600-45	47/26
FY_x 900-45	63/26
FY_x 1100-45	73/26
FY_x 800-60	73/26
FY_B 1100-60	84/26
FY_B 2000-45	84/26

FRD outline

IGCT & FRD Technologies

Buffer layer PIN

Anode transparent emitter

Ion implantation diffusion

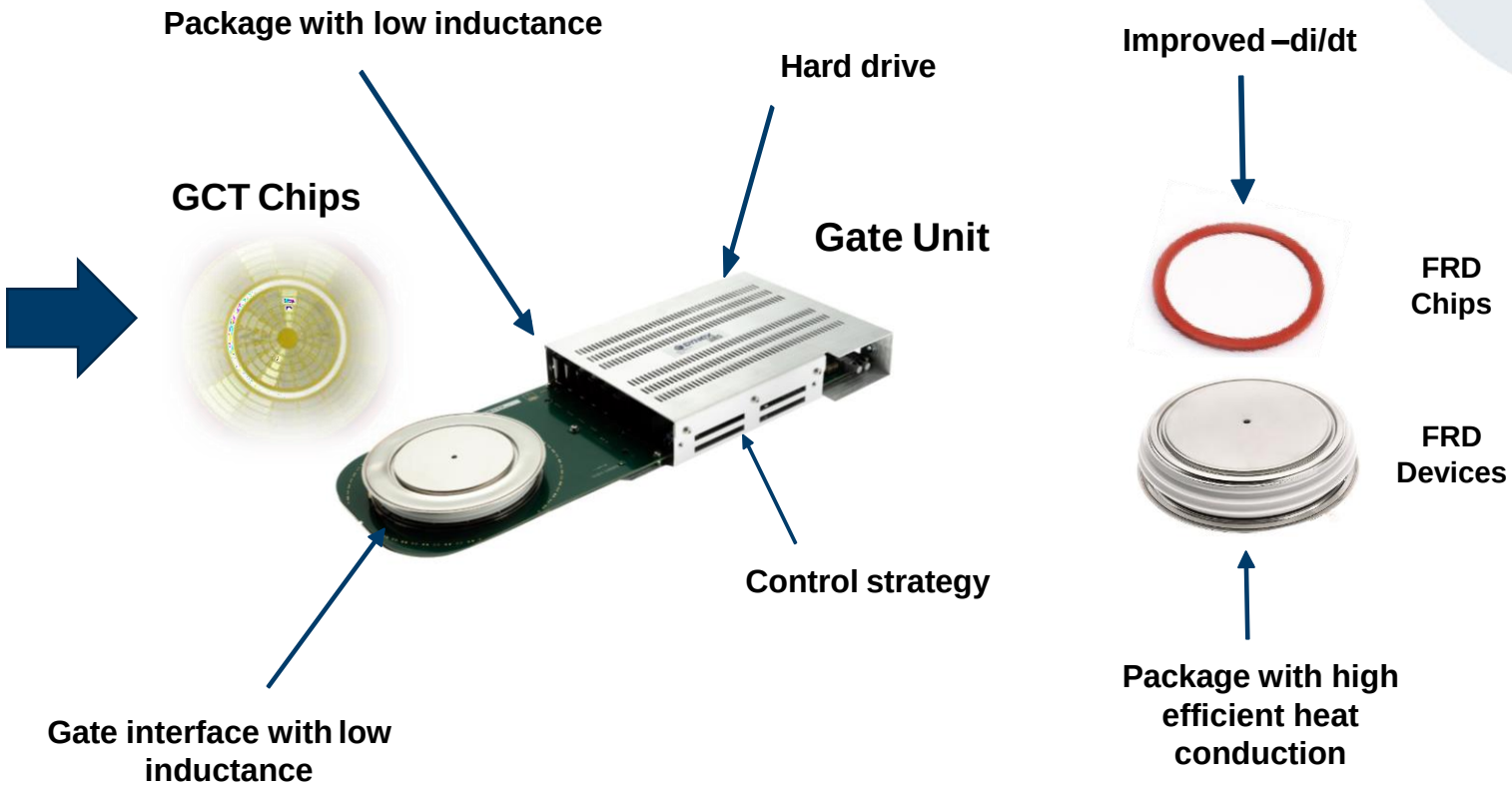
Multi-layer precision lithograph

Fingers chemical grooving

Fingers chemical grooving

Proton irradiation

RC isolation



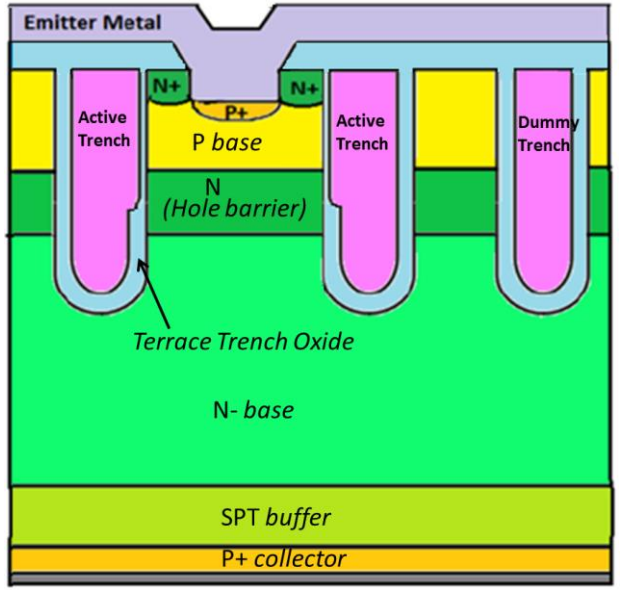
IGBT Module for HVDC

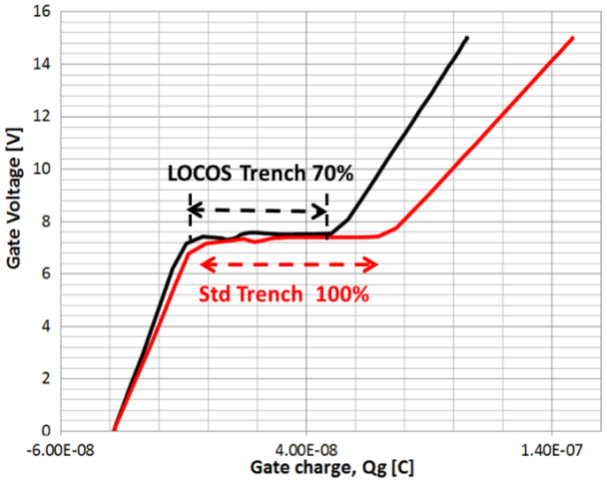
New Dynex HV-IGBT Trench Gate Technology

Low Q_G Terrace Trench Oxide – Trench IGBT (TTO-TIGBT)

- ✓ Enhancement of LOCOS process
- ✓ Low gate charge (Q_G)
- ✓ Improved E_{ON} & E_{OFF}
- ✓ Improved RBSOA (Reverse Bias Safety Operation Area)
- ✓ Increased Short circuit stability (Type-2)
- ✓ Improved gate oxide reliability
- ✓ Enhanced dV/dt capability
- ✓ Competitive $V_{CE(sat)}$
- ✓ Standard (S) and Fast (F) variants available
- ✓ Patented structure and process

Technology implemented on new 3.3kV, 4.5kV and 6.5kV products





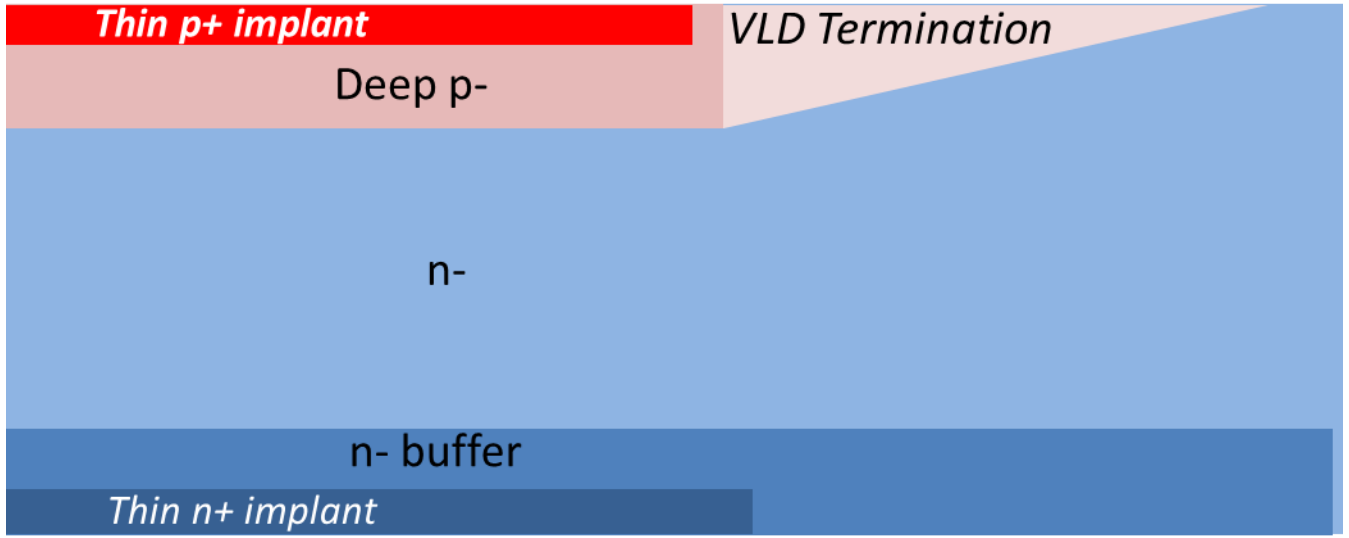
New Dynex HV Diode Technology

Masked Cathode FRD

Improved RBSOA

- ✓ 3.5MW Switching Capability!
- ✓ Beats Infineon and other competitors

Oscillation free



IGBT PressPack for HVDC

Press Pack

Press-pack IGBTs are an alternative to isolated-base plastic modules. Instead of the wire bonds and solder joints used in isolated-base modules, press-packs rely on the application of force by an external clamping system, to make contact to the chips.

They are the device of choice for applications that require series operation of IGBT devices, since it is straightforward to assemble press-packs in series stacks - a common practice for press-pack thyristors and diodes.

Ratings of press-pack IGBTs typically extend to higher currents than isolated-base modules and can cater for applications with higher current demands without the need for paralleling of devices.

Two of the most important aims in press-pack IGBT design are to ensure uniform distribution of contact pressure across all chips within the device, and to protect the gate microstructure beneath the emitter contact surface of the IGBT chips.

Dynamic Load Balancing (DLB)

Maximises safe operating area, gives high reliability and improves ease of use compared to conventional press-pack IGBT designs.

Silver Sintering Bonding

Applied to basic units between the chip and adjacent molybdenum platelets ensures outstanding reliability and improved thermal performance.

Silicone Edge

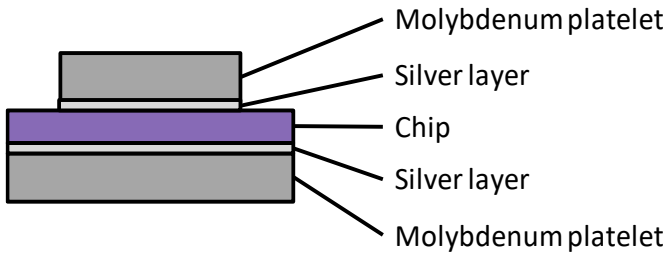
Passivation applied to Dynex's press-pack chips and a hermetically sealed housing gives robust high voltage blocking performance

Dedicated Auxiliary Emitter

Connection ensures synchronisation of gate drive signals between chips, mitigating the effects of power circuit di/dt on the driver circuit.

Silver Sintered Basic Units

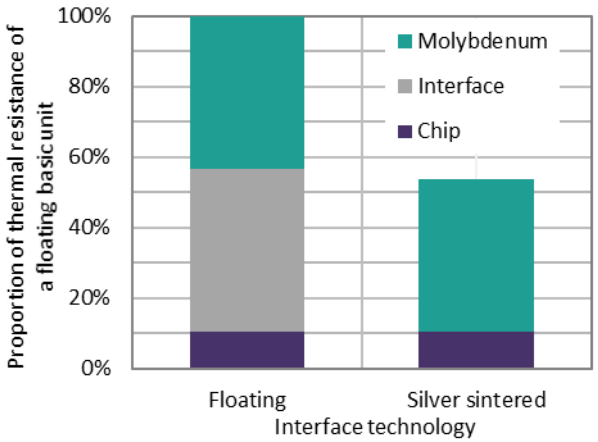
IGBT basic units using a floating construction exhibit unsatisfactorily variable reliability and high infant mortality rates. Dynex's press-pack IGBT basic units employ silver sinter bonding technology to bond the adjacent molybdenum platelets to the chips and overcome these limitations.



A cross-section of a Dynex silver sinter bonded basic unit.

Bonding the components together in this manner makes it impossible for fretting of the contact surfaces of the chips to occur, giving robust protection to the IGBT microstructure, yielding ultra-high reliability.

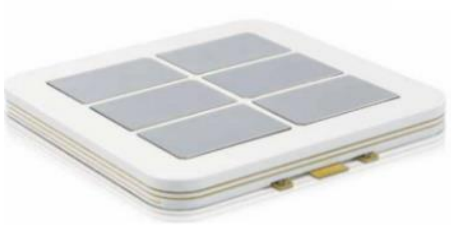
The replacement of dry interfaces with layers of silver also reduces the thermal resistance of the basic units significantly.



A cross-section of a Dynex silver sinter bonded basic unit.

As a result, Dynex's press-pack IGBTs demonstrate exemplary stability at high voltages and high temperatures.

Press-pack IGBT Key Features



- Flexible spring press
- Sub-module structure (multi-chips)
- Non-hermetic package structure
- The current maximum capacity is 3000A/4500V (including anti- parallel diodes)

- Flexible spring press
- Sub-module structure (single-chip)
- Hermetic package structure
- The current maximum capacity is 3000A/ 4500V (including anti-parallel diodes)

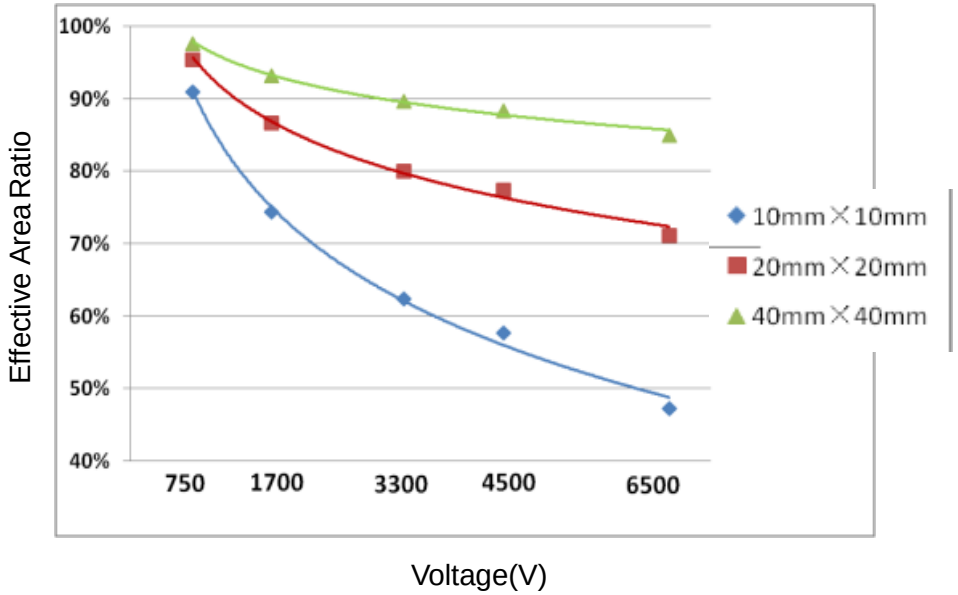
- Rigid press
- Hermetic ceramic package
- The current maximum capacity is 3000A/4500V (no anti-parallel diode)

Press Pack IGBT Overview

- Large scale chip, larger effective area, and higher current capability;
- Reduce number of parallel dies, improve reliability.

Manufacturer	CRRC （TG3000SW45ZC-P200）	Competitor A （p/n xxxx）
Chip size/mm^2	21*21	14*14
Effective Size /mm^2	18.4*18.4	12*12
IGBT Dies Quantity	24	48
Effective Area/mm^2	8125	6912
	117.5%	100%

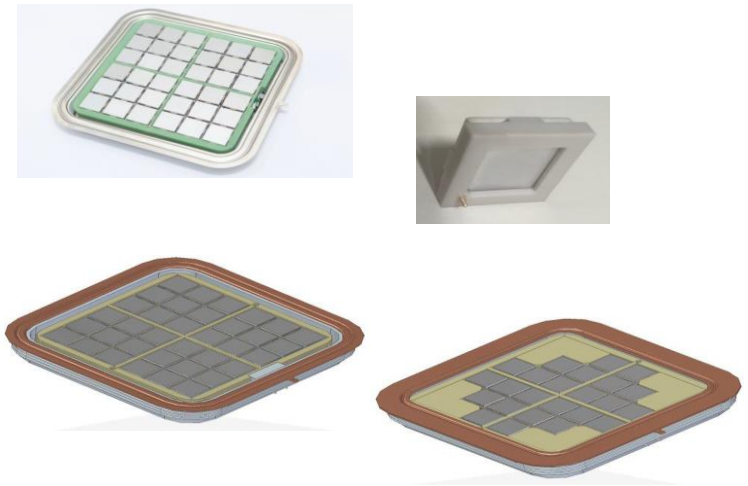
Comparison of Effective Area



Effective Area Ratio vs Voltage

Press-pack IGBT Overview

- Hermetic ceramic package structure
- A mature thyristor structure of hermetic ceramic package is adopted, the filling of nitrogen and inert gas is able to prevent moisture from entering;
- In Competitor A package structure, there is potential gap between sub-module and module due to the structure of coating plate and silicone encapsulation



Press-pack IGBT

Competitor 1 Press-pack IGBTs

Press-pack IGBT Overview

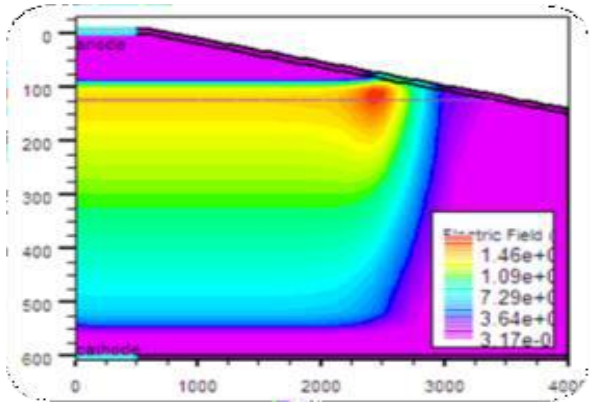
- Key Parameters Comparison
- Eoff and Erec are lower than competitor 1 modules, Eon is slightly higher than competitor 1modules;
- Overall loss is slightly lower than competitor 1 modules.

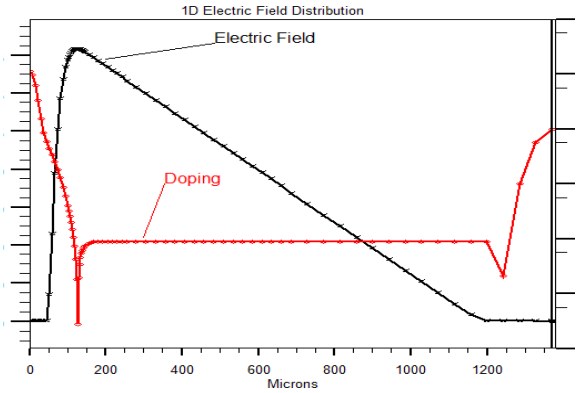
Key Parameters（25℃）	Symbol	Unit	CRRC	Competitor A
Turn-on Loss	E_{on}	J	19.70	17.73
Turn-off Loss	E_{off}	J	16.40	20.95
Reverse Recovery Loss	E_{rec}	J	4.01	4.36
Overall Switching Loss	E_{tot}	J	40.01	43.04

Technology Improvement + Research & Development

Technology Platform Improvement

Design

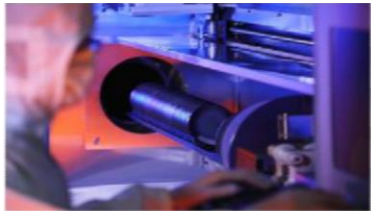


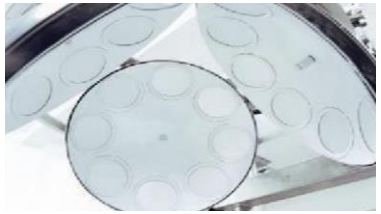


- ✓ In 2012, Two R&D centres were formed in Lincoln and Zhuzhou - designing and developing coherently
- ✓ In 2012, Dynex applied simulation tools SILVACO into the process and device simulation
- ✓ In 2013, the simulation lab was built to optimise the design, process and characteristic in full dimensions.

Technology Platform Improvement

Process





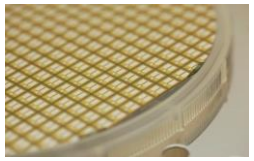
- ✓ The diffusion system enables the single process with large batch processing capacity and increased parameter uniformity
- ✓ The control of the gel, baking and high-precision alignment exposure equipment is automated with high chip line alignment precision
- ✓ The high-vacuum thick-film aluminum electron beam evaporation equipment ensures adhesion and uniformity of the aluminum layer and fatigue resistance
- ✓ A 12MeV electron irradiation linear accelerator with high control precision is used to optimise, match and coordinate the relationship of various parameters of the device to ensure high reliability of high-voltage series-parallel application
- ✓ The annual production capacity of bipolar devices is 600,000pcs.

Development Plan

IGBT

- ✓ Upgraded IGBT facility to increase capacity and offer a wider range of devices to cater to automotive market
- ✓ IGBT development driven by rail, power grid, renewable energy
- ✓ New generation of IGBTs: RC, S-junction, MOSFET, Power IC

SiC



- ✓ Start production on 6-inch SiC line
- ✓ Develop 650V-4500V SiC SBD, SiC MOSFET and modules
- ✓ Pilot applications in rail, auto, renewable energy

Bipolar

- ✓ Improve device performance by power grid application
- ✓ Develop super size IGCT and FRD for offshore wind power and industrial equipment
- ✓ World market leading

Part 4

R&D Plan – New Product

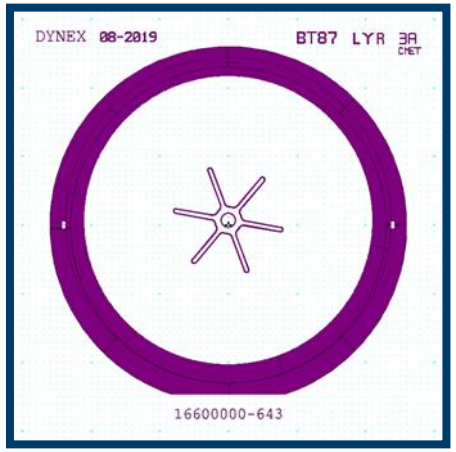
Up to 7 inch HVDC thyristor

Part Number	V_{DSM}/V_{RSM}(V)	Condition
KP_F 6500- 85	8500	Tvj = 25, 125 °C IDRM, IRRM≤400mA VDRM = VDSM VRRM = VRSM

Smaller HVDC thyristor

Part Number	V_{DSM}/V_{RSM}(V)	Condition
KP_A 700-85 KP_X 1200-85 KP_B 1400-85 KP_C 1800-85	8500	T_{vj} = 25, 125 °C IDRM, IRRM≤400mA VDRM = VDSM VRRM = VRSM

6.5kV RAByT – Development Status



ACR4000WR65

Fabrication

Optimising diffusion profile

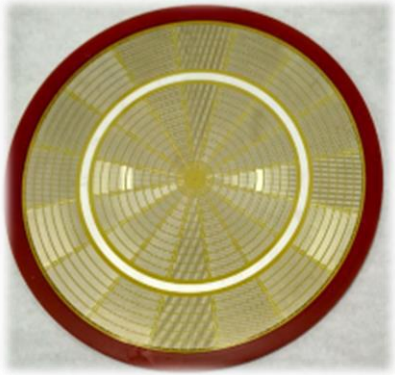
- Varying buffer concentration

Two mask options

- Original 3 arms
- New 6 arm (improved current spreading)
- Designed to optimise bypass performance

IGCT R&D Roadmap

6-inch GCT chip



6kA~8kA rating GCT		**RB IGCT**	**6kV, 9kV rating IGCT**	
V_{DRM}: 4500 (V) I_{TGQM}: 8000 (A) 6inch As GCT	V_{DRM}: 6000 (V) I_{TGQM}: 2000 (A) 4inch RB GCT	V_{DRM}: 6000 (V) I_{TGQM}: 6000 (A) 6inch As GCT	V_{DRM}: 9000 (V) I_{TGQM}: 3000 (A) 4inch As GCT	V_{DRM}: 4500 (V) I_{TGQM}: 6000 (A) 6inch RCGCT