ISPSD: A 30 year Journey in Advancing Power Semiconductor Technology

Ayman Shibib, IEEE Fellow
Vishay Siliconix, Santa Clara, CA, USA
Email: ayman.shibib@Vishay.com

Leo Lorenz, IEEE Fellow
ECPE/Infineon, Germany

Hiromichi Ohashi
NEPRC-J, Japan
Email: oh@nperc-j.oo.jp

ISPSD: A 30 year Journey in Advancing Power Semiconductor Technology

- Establishment and evolution of ISPSD
  - Establishing ISPSD as premier Power Device Conference
  - Combining power discretes and ICs in one conference
  - Globalization of ISPSD and annual site rotation
  - ISPSD firsts
  - Technical Committee and sub-committees
- Highlights of technical contributions of ISPSD to field of Power Devices and ICs
- Accomplishments and future prospects of ISPSD

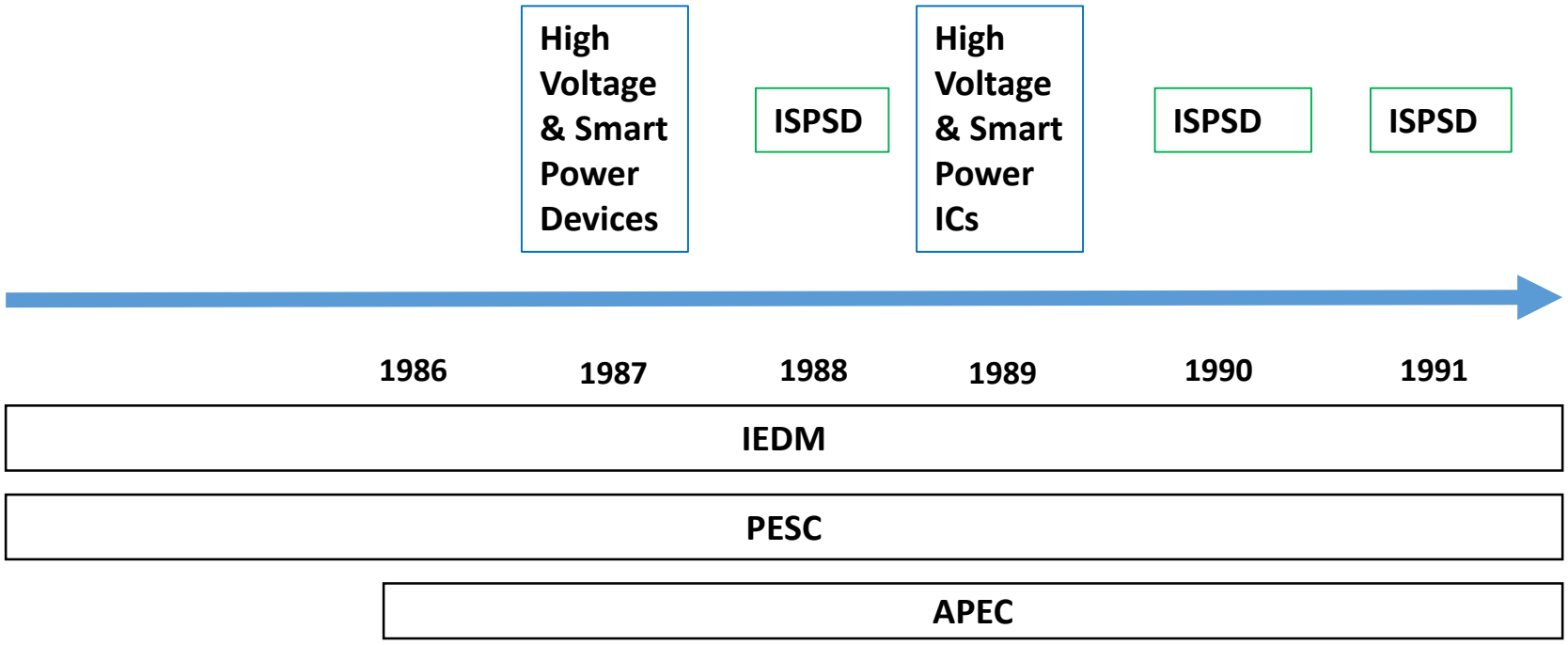
ISPSD early days

- In response to the growing need to focus on Power Devices and technologies, several symposia were established in the mid to late 1980s by different technical societies
- Areas of focus
  - High voltage high power discretes
  - Low voltage power discretes
  - Integrated power devices (LV and HV) and ICs
  - Bipolar and MOS controlled devices and technologies
  - RF power devices
  - Non-silicon based devices
  - Rugged devices with wide Safe-Operating-Area
- Challenge: combining high voltage high power devices and integrated power devices and ICs

Establishing ISPSD

- Electronics division of the ElectroChemical Society (ECS) sponsored a symposium for Smart Power Devices in its general Spring 1987 meeting in Philadelphia, PA.
- In 1988, IEE-J sponsored the “International Symposium on Power Semiconductor Devices” in Tokyo, Japan.
- In 1989, ECS sponsored another “High Voltage & Smart Power ICs” in Los Angeles, CA.
- In 1990, IEEE Electron Devices Society co-sponsored ISPSD with IEE-J in Tokyo, Japan.
- In 1991, the 3rd ISPSD in was held in USA (Baltimore), fully sponsored by IEEE Electron Devices Society (EDS).
- In 1994 , the 6^{th} ISPSD was held in Europe (Davos, Switzerland) co-sponsored by ETH, IEEE EDS, IEE-J and EPE. ISPED stared as a full global conference in a three-way rotation with Japan (Asia area), USA (America area) and Europe.

ISPSD beginning era



ISPSD Sites: the first decade

1988 1st ISPSD held in Tokyo, **Japan**

1990 2nd ISPSD held in Tokyo, **Japan**

1991 3rd ISPSD held in Baltimore, MD, **USA**

1992 4th ISPSD held in Tokyo, **Japan**

1993 5th ISPSD held in Monterey, CA, **USA**

1994 6th ISPSD held in Davos, **Switzerland**

1995 7th ISPSD held in Yokohama, **Japan**

1996 8th ISPSD held in Maui, Hawaii, **USA**

1997 9th ISPSD held in Weimar, **Germany**

1998 10th ISPSD held in Kyoto, **Japan**

ISPSD Sites: the second decade

1999 11th ISPSD held in Toronto, **Canada**

2000 12th ISPSD held in Toulouse, **France**

2001 13th ISPSD held in Osaka, **Japan**

2002 14th ISPSD held in Santa Fe, NM, **USA**

2003 15th ISPSD held in Cambridge**, UK**

2004 16th ISPSD held in Kitakyushu, **Japan**

2005 17th ISPSD held in Santa Barbara, CA, **USA**

2006 18th ISPSD held in Naples, **Italy**

2007 19th ISPSD held in Jeju, **South Korea**

2008 20th ISPSD held in Orlando, FL, **USA**

ISPSD Sites: the third decade

2009 21th ISPSD held in Barcelona, **Spain**

2010 22th ISPSD held in Hiroshima, **Japan**

2011 23th ISPSD held in San Diego, CA, **USA**

2012 24th ISPSD held in Bruges, **Belgium**

2013 25th ISPSD held in Kanazawa, **Japan**

2014 26th ISPSD held in Waikoloa, Hawaii, **USA**

2015 27th ISPSD held in **Hong Kong, China**

2016 28th ISPSD held in Prague, **Czech Republic**

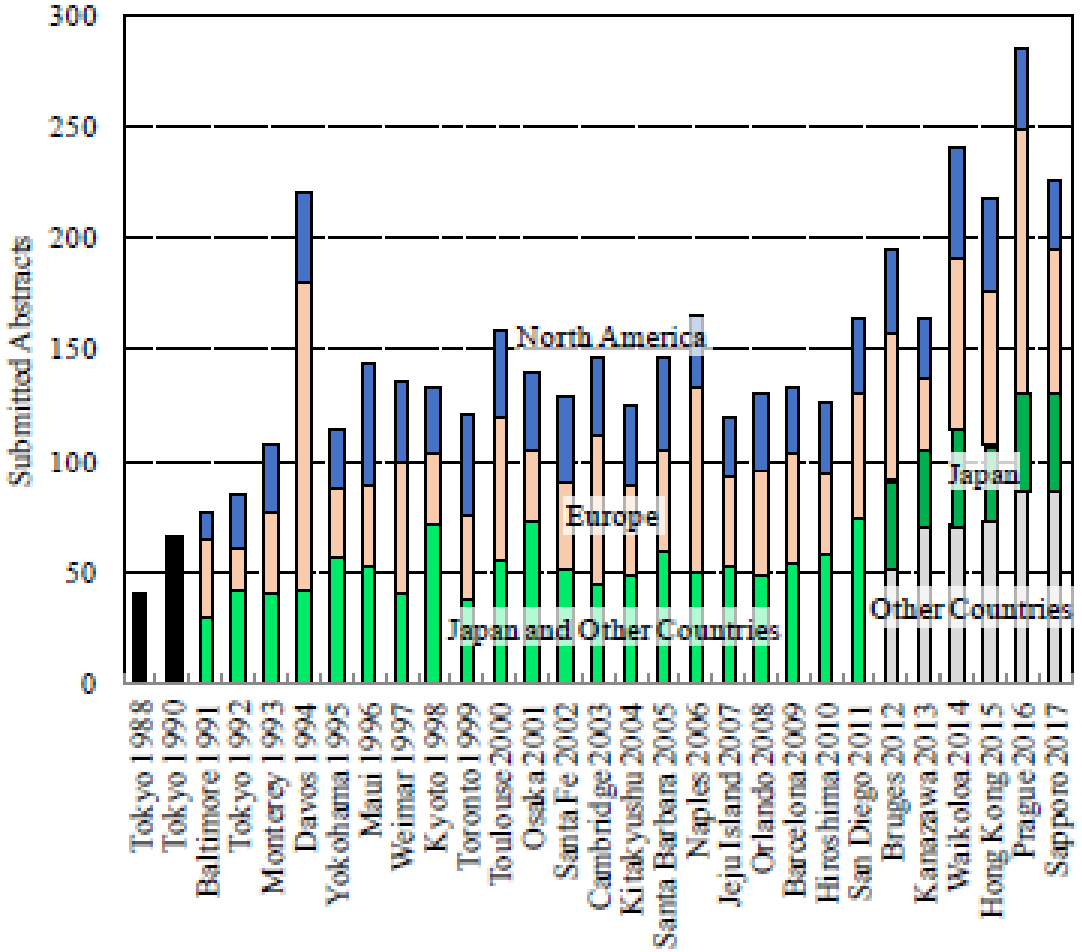
2017 29th ISPSD held in Sapporo, **Japan**

2018 30th ISPSD held in Chicago, IL, **USA**

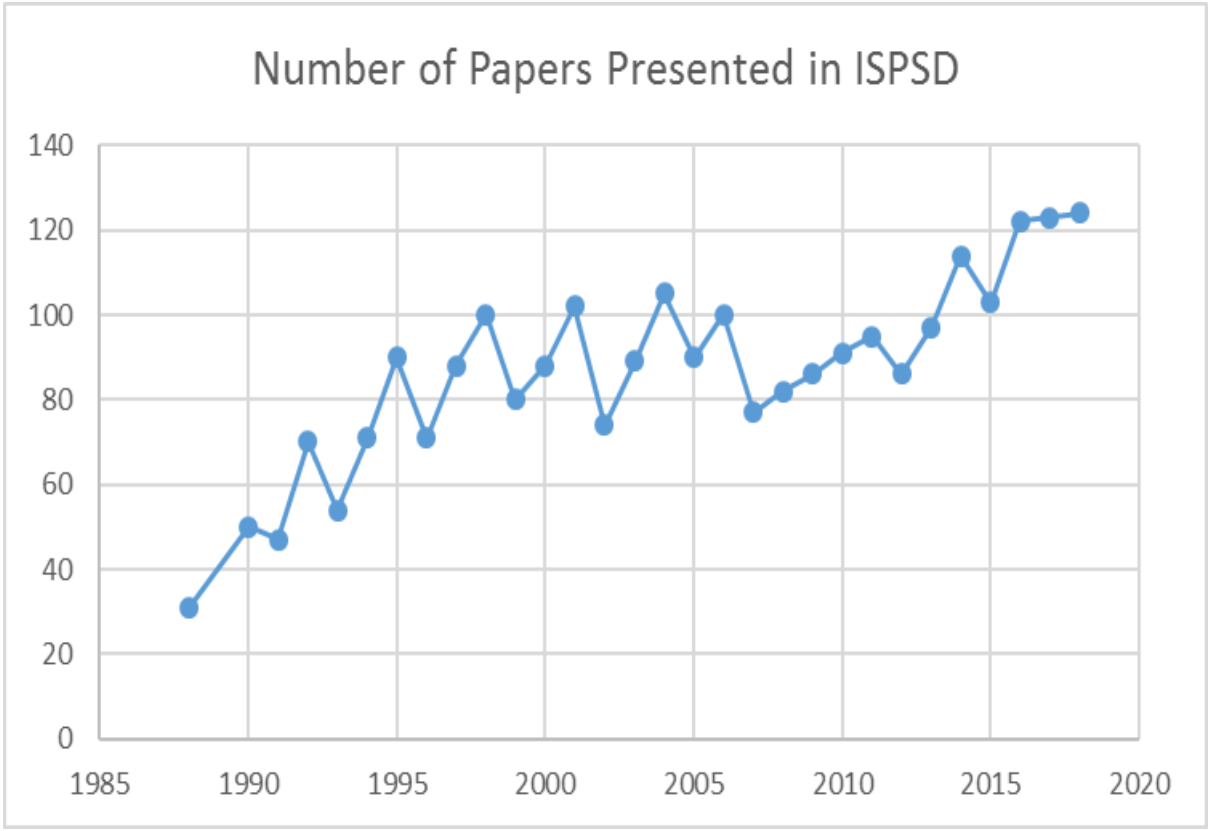
ISPSD's 30th Anniversary: ISPSD Firsts

- **1988** First ISPSD conference held in **Japan**: Tokyo, Japan
- **1990** First ISPSD conference with "**ICs**" added to the conference's title
- **1991** First ISPSD conference held in **US** and fully sponsored by IEEE Electron Devices Society: Baltimore, Maryland
- **1994** First ISPSD conference held in Europe: Davos, **Switzerland**
- **1996** First ISPSD conference held in US but outside the contiguous states: Maui, **Hawaii**
- **1999** First ISPSD conference held in North America but not in the US: Toronto, **Canada**
- **2007** First ISPSD conference held in Asia but not in Japan: Jeju Island, **South Korea**
- **2015** First ISPSD conference held in Asia on an optional 4th year rotation scheme: **Hong Kong**, China

Number of abstracts submitted to ISPSD per year



Ref: ISPSD 2017


Number of Papers Presented in ISPSD
140
120
100
80
60
40
20
0
1985
1990
1995
2000
2005
2010
2015
2020

ISPSD Development

- As the number of papers submitted from “other countries” increased after 2010, the Advisory Committee adopted a 4th year rotation based on proposals to sponsor ISPSD from other countries outside of US, Japan and Europe starting in 2012
- In 2015 ISPSD 4th year rotation was implemented in Hong Kong, China
- Another accepted 4th year proposal for 2019 ISPSD is for Shanghai, China

Technical Program Committees of ISPSD

- **1988** to **2004** one technical committee reviewed all submitted papers
- In **2005** subcommittees were formed to review papers in three categories:
  - Low Voltage and RF
  - High Voltage
  - Integrated Power
- In **2008** Wide Bandgap subcommittee was added
- In **2010** Module & Package subcommittee was added
- In **2016** Wide Bandgap subcommittee split into two:
  - GaN and Other Nitrides
  - SiC and Other

Technical Highlights of ISPSD

- In the first decade: BCDMOS technologies
- In the second decade: Super Junction devices
- In the third decade: GaN
- In the inter-decades: MOS controlled power devices
- Additional highlights

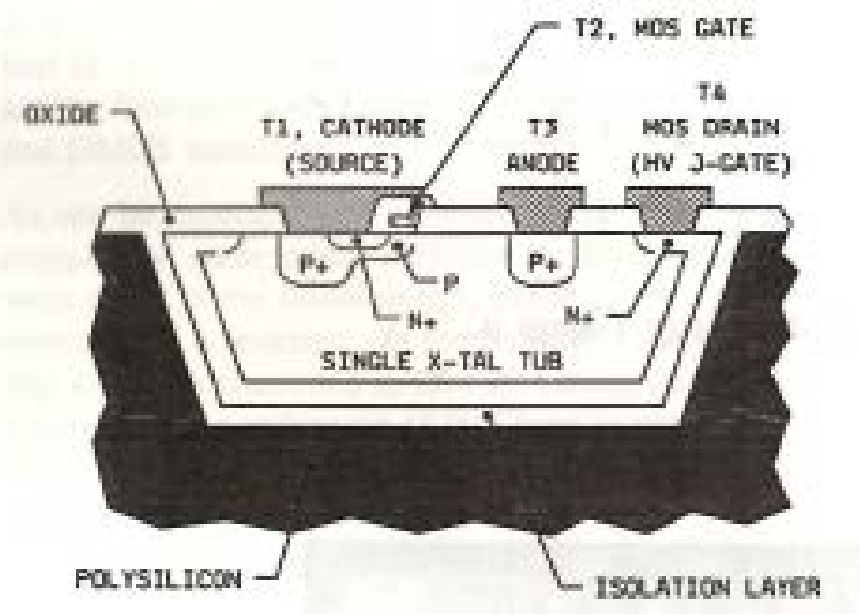
ISPSD Highlights: BCDMOS technology

- **1988** ISPSD Cini et al, p88, **Junction isolated** BCDMOS technology with voltages from 20V up to 250V
- **1988** ISPSD Okabe et al, p96, **semi-well isolated** up to 70V
- **1988** ISPSD Kawamura et al, p101, **400V** high voltage Pch and Nch and CMOS with N+ isolation
- **1988** ISPSD Gammel et al, p117, 300V **Dielectrically Isolated (DI)** BCDMOS technology for telecom line interface circuits using **LIGBTs**
- **1988** ISPSD Sugawara et al, p121, 400V **DI** BCDMOS for half bridge circuits

- **1990** ISPSD Suda et al, p49, use of the **DI Pch and CMOS** technology for **automotive** application
- **1990** ISPSD Tsuchiya et al, p60, **junction isolated** DMOS and LIGBT integration for **flat panel displays**
- **1990** ISPSD Sakurai et al, p66, **DI LIGBT** for output stage of **monolithic three-phase inverter IC**
- **1990** ISPSD Bruning et al, p72, off-line 500V **junction isolated full bridge driver** for motor control

- **1991** ISPSD Merchant et al, p31, high voltage (>700V) in **thin SOI** devices
- **199**1 ISPSD Mizoguchi et al, p40, **DI** with 600V and 25A integrated **vertical IGBT**
- **1991** ISPSD Masquelier et al, p56, BiCMOS Process with **200V 60 MHz PNP**
- **1991** ISPSD Narayanan et al, p181, **2.5 um CMOS compatible 250V LIGBT**

Dielectric Isolation (DI) BCDMOS technology used for telecom circuits



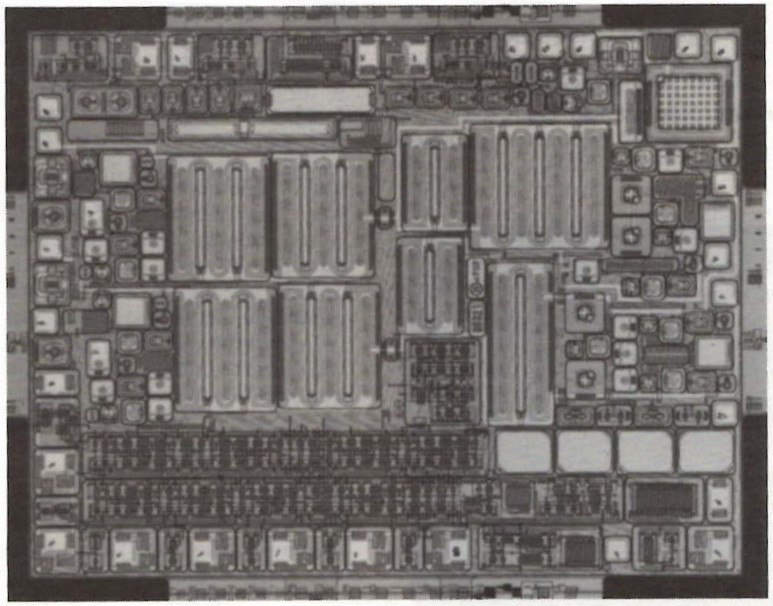


Figure 2. Photomicrograph of the High Voltage IC.

Ref: 1988 ISPSD Gammel et al, p117

ISPSD Highlights: BCDMOS technology … cont

- **1992** ISPSD Rumennik, p322, **1200V BiCMOS** technology
- **1992** ISPSD Nakagawa et al, p328, **500V three phase inverter ICs** based on **DI**

- **1993** ISPSD Ajit et al, p230, **1200V high-side** lateral MOSFET in junction isolation
- **1993** ISPSD Fujishima et al, p298, high density, **1.5 um CMOS**, Bi-CDMOS applied to motor drivers

- **1994** ISPSD Corsi et al, p329, VLSI compatible BICMOS technology for **automotive interface design**
- **1994** ISPSD Li et al, p355, Submicron (**0.8 um**) BiCMOS compatible MOS transistors

- **1995** ISPSD Shibib et al, p48, Cost-Effective Smart Power BiCMOS technology in **DI**
- **1995** ISPSD Ohguro et al, p114, high frequency **0.35 um** gate length power NMOSFET

- **1997** ISPSD Carter et al, p325, HVIC for high frequency (**13.56 MHz**) power converters
- **1997** ISPSD Aliahmad et al, p329, Short-Loop SLIC in **submicron (0.8 um) BiCMOS**
- **1997** ISPSD Nezar et al, p333, Submicron (**0.8 um**) Bi-CMOS-DMOS for 20-30V and 50V applications

- **1998** ISPSD Contiero et al, p11, Smart power approaches VLSI complexity (**0.35 um**) demonstrating **3 levels of metal and 40V**

ISPSD Highlights: Super Junction

- **1998** ISPSD Fujihira et al, p423, **Simulated superior performance** of semiconductor super junction devices

- **1999** ISPSD Lorenz et al, p3, demonstration of SJ by **multi-layer epitaxy**
- **1999** ISPSD Shenoy et al, p99, studied effect of **charge imbalance** on characteristics of SJ MOSFET

- **2000** ISPSD Saggio et al, p65, innovative technology for **high voltage** power MOSFETs
- **2000** ISPSD Ludikhuize, p12, review of RESURF technology
- **2000** ISPSD Bai et al, p257, **junction termination technique** for super junction devices

- **2001** ISPSD Disney et al, p399, **800V lateral MOSFET** with dual conduction paths
- **2001** ISPSD Napoli et al, p339, design of 1000V merged **PiN Schottky** diode using super junction layer
- **2001** ISPSD Udrea et al, p129, experimental demonstration of **6.5 KV 3D RESURF** super junction termination

- **2002** ISPSD Nassif-Khalil et al, **super junction LDMOST** in silicon-on-sapphire technology

ISPSD Highlights: Super Junction … cont

- **2003** ISPSD Yamauchi et al, p207, **super junction p-n junction** fabricated by trench filling

- **2004** ISPSD Rub et al, p455, 550V super junction 3.9 Ohm.mm2 transistor formed by **25 MEV masked Boron implant**

- **2005** ISPSD Hattori et al, p189, 200V super junction MOSFET fabricated with **trench filling**
- **2005** ISPSD Antoniou et al, p101, super junction **bipolar transistor** for ultra-fast switching
- **2005** ISPSD Udrea et al, p267, **ultra-fast LIGBT and super junction** devices in membrane technology

- **2008** ISPSD Sugi et al, SJ MOSFET by **deep trench etching**
- **2008** ISPSD Disney et al, p160, **JFET effect** in super junction devices
- **2008** ISPSD Oh et al, p299, experimental investigation of **650V super junction IGBTs**

ISPSD Highlights: GaN

- **2003** ISPSD Matocha et al, p54, high voltage **accumulation-mode lateral RESURF** GaN MOSFET (180V) on SiC
- **2003** ISPSD Yoshida et al, p58, **AlGaN/GaN 8 mOhm.cm2** HFET for an inverter circuit

- **2009** ISPSD Wong et al, p57, **Integrated voltage reference and comparator** circuits for GaN smart power chip technology

- **2011** ISPSD Hilt et al, p239, normally-off high voltage **p-GaN gate HFET with carbon-doped buffer**

- **2012** ISPSD Hilt et al, p345, **impact of buffer composition** on dynamic on-state resistance of AlGaN/GaN HFET

- **2014** ISPSD Wong et al, p55, AlGaN/GaN MIS-HFET with **improvement in high temperature gate bias** stress-induced reliability
- **2014** ISPSD Wang et al, p430, a GaN **pulse width modulation** integrated circuit

- **2015** ISPSD Lidow, p1, **GaN transistors giving new life** to Moore's law,
- **2015** ISPSD 2 full GaN sessions (**8 papers**) and total of **16 total GaN papers**
  - Moens et al, p37, **carbon doping** impact on dynamic Rds and of state leakage
  - Kaneko et al, p41, **current collapse free** 850V GaN-GIT
  - Nakajima et al, p357, GaN based **monolithic power IC** technology with **Pch and Nch 2D**

ISPSD Highlights: GaN … cont

- **2016** ISPSD **2 full GaN sessions (8 papers) and 22 total GaN papers**
  - Okita et al, p23, new **gate recess and regrowth gate technology** for process stability of GaN-GITs
  - Shen et al, p79, experimental demonstration of **solid state circuit breaker using 650V GaN based** monolithic bidirectional switch
  - Naka et al, p259, **UIS withstanding capability** and mechanism of high voltage GaN-HEMTs
  - Moens et al, p455, AlGaN/GaN power device technology for high current **above 100A** and high voltage of **1.2 KV**
  - Oka et al, p459, **1.2 KV Vertical GaN trench MOSFETs** on bulk GaN substrate

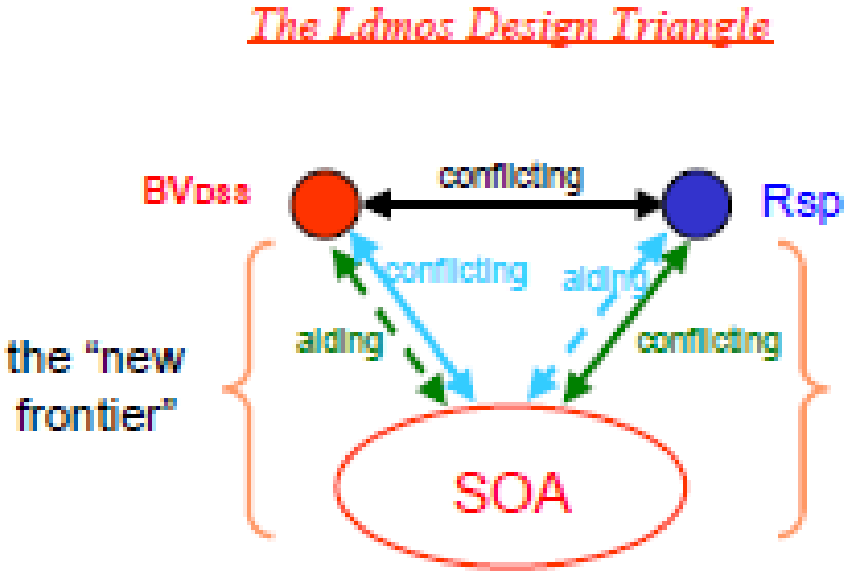
- **2017** ISPSD Kinzer, p19, GaN power IC technology: past, present and future
  - **2 full GaN sessions (7 papers) and total of 20 GaN papers**
  - Moens et al, **negative dynamic Ron** in ALGaN/GaN power devices
  - Yang et al, p101, **buffer trapping induced Ron** degradation and the role of electron injection from silicon substrate
  - Fernandez et al, p455, **Short-Circuit capability in p-GaN** HEMT and GaN MISHEMTs

ISPSD Highlights: MOS Controlled Power Devices

- **1990** ISPSD Baliga, p117, MOS controlled **emitter switched thyristor**
- **1994** ISPSD Harada et al, p411, 600V **trench** IGBT in comparison with planar IGBT
- **1994** ISPSD Kabza et al, **Cosmic Radiation** as a Cause for Power Device Failures and Possible Countermeasures
- **1994** ISPSD Thapar et al, p177, New IGBT structure with **wider SOA**
- **1995** ISPSD Kitagawa et al, p486, A **4500V injection enhanced** insulated gate bipolar transistor (IEGT)
- **1998** ISPSD Laska, p433, **1200V-Trench-IGBT** study with square short circuit SOA
- **2000** ISPSD Laska, p355, The **field stop IGBT**(FS IGBT) – a new power device concept with a great improvement potential
- **2006** ISPSD Nakagawa, p5, Theoretical Investigation of **Silicon Limit** Characteristics of IGBTs
- **2009** ISPSD Rahimo, p283, The **Bi-Mode** Insulated Gate Transistor (BIGT) a Potential Technology for Higher Power Applications
- **2010** ISPSD Hille, p33, **Failure mechanism and improvement** potential of IGBT's short circuit operation
- **2015** ISPSD Wolter, p105, Multi-dimensional Trade-off Considerations of the **750V Micro Pattern Trench IGBT** for Electric Drive Train Applications
- **2016** ISPSD Eikyu et al, p211, On the **Scaling Limit of the Si-IGBTs** with Very Narrow Mesa Structure
- **2017** ISPSD Takeuchi et al, p57, A Novel **Hybrid Power Module** with Dual Side-Gate HiGT and SiC-SBD

ISPSD Highlights: LDMOS SOA

Series of papers addressing the safe Operating Area (SOA) of LDMOS as part of the device design and optimization. Also the improvement of LDMOS SOA, 2005 ISPSD, p327 & 2006 ISPSD, p89.



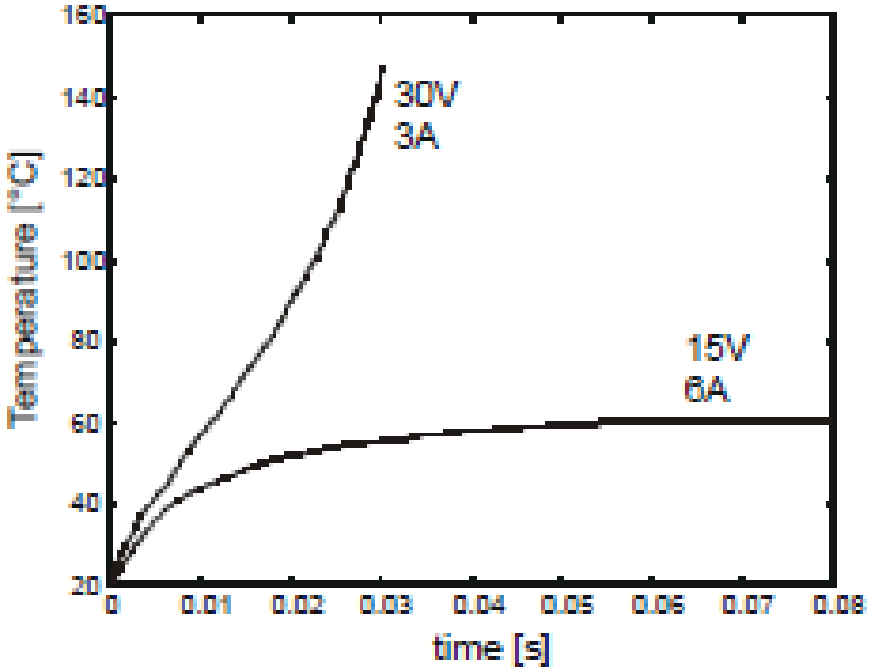
2002 ISPSD, Hower, p1

Ref:

1999 ISPSD, Hower et al, p55
2000 ISPSD, Hower et al, p345
2001 ISPSD, Hower et al, p153
2002 ISPSD, Hower, p1
2005 ISPSD, Hower et al, p327
2006 ISPSD, Lin et al, p89

ISPSD Highlights: Spirito Effect

Series of papers from Spirito's team in ISPSD **1999**, **2002** and **2005**, reported on the thermal instability of high current discrete MOSFET devices indicating that it is not just the total power dissipation and the thermal package that determines the SOA. Thermal instability is set by the positive temperature coefficient of the drain current that results in a significant temperature rise leading to thermal runaway.
As a result of this, most LV MOSFET datasheets had to add this "**Spirito Effect**" limit to the standard SOA characteristics.



2002 ISPSD, Spirito et al, p269

Ref:
1999 ISPSD, Breglio et al, p233
2002 ISPSD, Spirito et al, p269
2005 ISPSD, Spirito et al, p183

Two ISPSD most cited papers (by other papers)*

COOLMOS™-a new milestone in high voltage power MOS
L. Lorenz; G. Deboy; A. Knapp; M. Marz
Power Semiconductor Devices and ICs, 1999. ISPSD '99. Proceedings., The 11th International Symposium on
Year: 1999
Pages: 3 - 10
Cited by: **Papers (105)** | Patents (13)

Analysis of the effect of charge imbalance on the static and dynamic characteristics of the super junction MOSFET
P. M. Shenoy; A. Bhalla; G. M. Dolny
Power Semiconductor Devices and ICs, 1999. ISPSD '99. Proceedings., The 11th International Symposium on
Year: 1999
Pages: 99 - 102
Cited by: **Papers (85)** | Patents (77)

* IEEE Xplore

Two ISPSD most cited papers (by patents)*

A new power W-gated trench MOSFET (WMOSFET) with high switching performance
M. Darwish; C. Yue; Kam Hong Lui; F. Giles; B. Chan; Kuo-in Chen; D. Pattanayak; Qufei Chen; K. Terrill; K. Owyang
Power Semiconductor Devices and ICs, 2003. Proceedings. ISPSD '03. 2003 IEEE 15th International Symposium on
Year: 2003
Pages: 24 - 27
Cited by: Papers (35) | **Patents (80)**

Analysis of the effect of charge imbalance on the static and dynamic characteristics of the super junction MOSFET
P. M. Shenoy; A. Bhalla; G. M. Dolny
Power Semiconductor Devices and ICs, 1999. ISPSD '99. Proceedings., The 11th International Symposium on
Year: 1999
Pages: 99 - 102
Cited by: Papers (85) | **Patents (77)**

* IEEE Xplore

Accomplishments of ISPSD

- Achieved the status of the premier conference on power semiconductor devices and ICs
- Established an international community of power device and related field experts that meet annually to exchange ideas, research and developments in the field
- Presented a regular forum to support students and newcomers to the field by offering latest research, courses, workshops and review papers

Future Prospects of ISPSD

- Big data centers and servers requiring efficient systems to reduce power consumption
- Requirements for thinner and smaller size efficient devices for mobile power
- Wireless charging
- E-Mobility and future renewable energy technologies
- SMART 3-D integration for high power density, high switching frequency and high reliability
- Ultra high power devices based on WB material for Green Energy solutions
- Expanded role of power devices to support the added functionality and interconnectivity.
- New applications requiring deep understanding and optimization of devices to meet special requirements
- Demographic change of development and manufacturing

Acknowledgement

To all authors of papers published in ISPSD Proceedings over the past 30 years and members of Technical, Organizing and Advisory Committees worldwide who volunteered their time, effort and technical expertise to ISPSD, **thank you!**