Research progress of SOI devices and modeling in SIMIT

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Shanghai Institute of Microsystem and Information Technology
Chinese Academy of Sciences

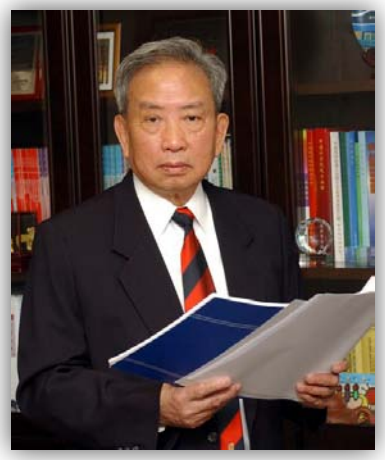
Jun. 27, 2016

Outline

- **Introduction of SOI Group**
- **Research results**
  - ✓ DC Device Model
  - ✓ RF Device Model
  - ✓ Research of SOI Device
  - ✓ Fruits of international cooperation
- **Summary**

Staff

Prof. Xi Wang
Academician of the Chinese Academy of Sciences



Prof. Shichang Zou
Academician of the Chinese Academy of Sciences

- Total 78 people
- 14 professors
- 10 associate Professors
- 38 graduate students

Research field

- **SIMIT research teams are actively driving new SOI technology development, e.g. material, device, process, design services, products etc., help to build up SOI ecosystem.**

SOI Material	• SiGe, Strain SOI • GaN, Graphene
SOI Design Service	• Process, Device, Modeling • PDK, Library, IP
SOI Circuit	• ASIC, FPGA, ADC, Switch
SOI Photonics	• AWG, MMI, High-end microprocessor

Achievements

100+ papers published, 150+ patents applied (including 50+ international), within the last 5 years.

the Prize of National Science & Technology Advancement (1st grade)

SOI Roadmap in SIMIT

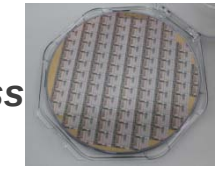
PD SOI Technology

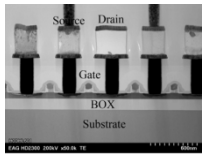
FD SOI Technology

Technology

0.13um SOI Logic Process

0.2um SOI RF Process





GLOBALFOUNDRIES

IBM

SIMIT

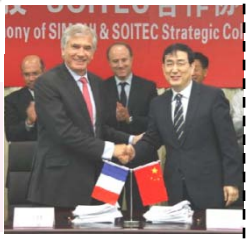
SITRI

simtao

imec

Substrates

Soitec



leti

Simox

SIMGUI

Smart cut

1980s

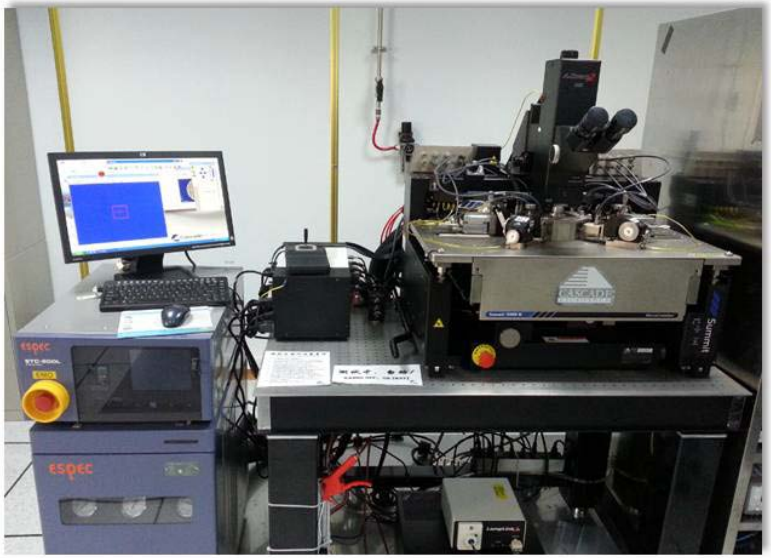
2000s

2014s

Model Laboratory - Hardware

- **Laboratory has the ability to test DC, RF and flick noise.**

Electromagnetic shielding room



Cascade Summit 12000 B-M

Agilent B1500A

Agilent B1542A

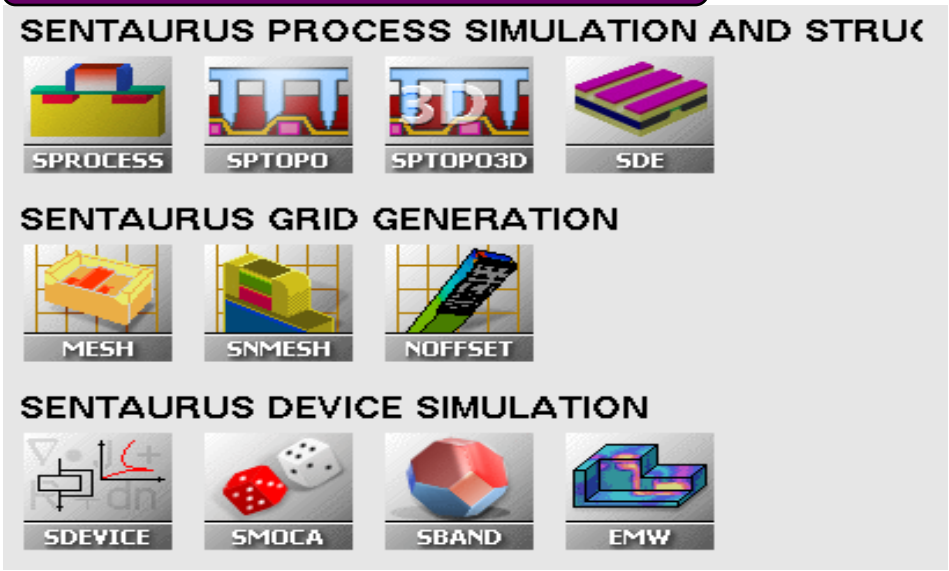
Cascade EDGE Module

Agilent N5244A PNA-X

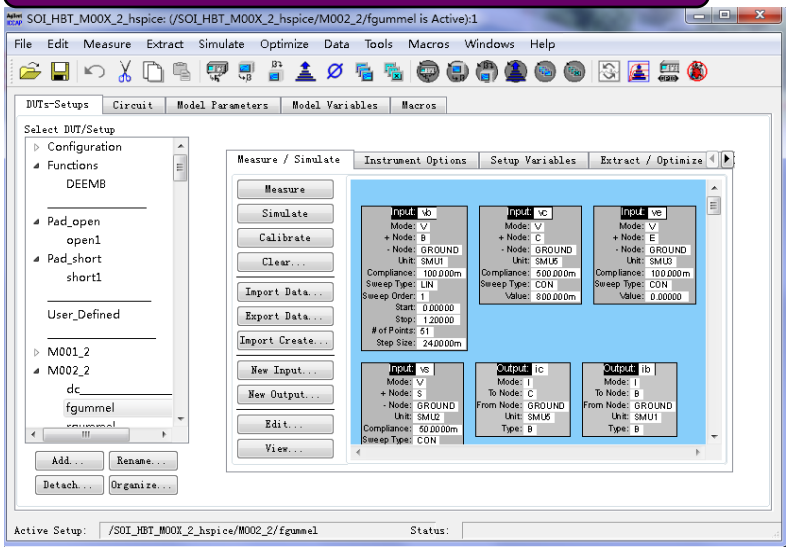
Model Laboratory - Software

- **Laboratory has a complete EDA solution for device modeling.**

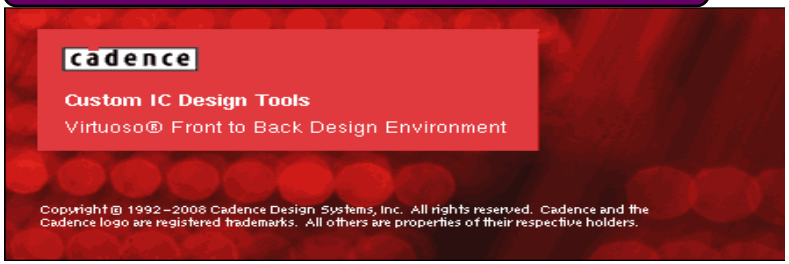
✓ Sentaurus TCAD Tool

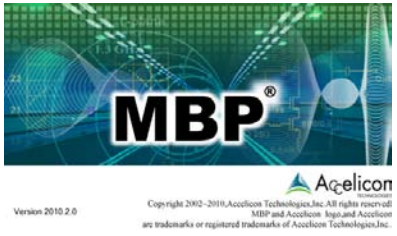


✓ Agilent Model Tool



✓ Cadence Tool





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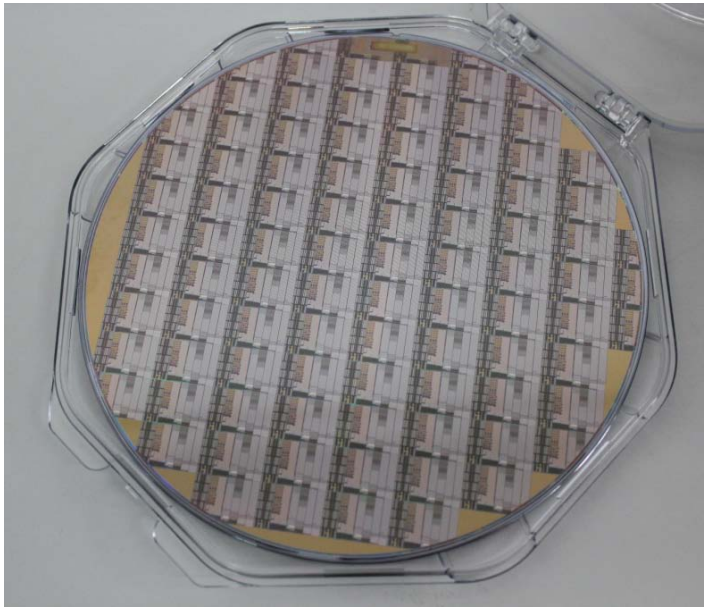
DC Device Model

- **We have extracted a complete DC Device Model for 0.13 um SOI Technology.**



Golden Wafer for SOI Device modeling

Device	•MOS（FB, TB, HB）, BJT, Resistor, Diode, MIM
Level	•70 (BSIM4SOI)
Effects	•FBE/GIFBE, SHE, Gate-leakage, GIDL
Geometry	•Core：L[0.13~10um], W[0.15~100um] •IO： L[0.35~10um], W[0.3~100um]
Temp.	•-55~125°C
Voltage	•Gate: [-1.32~1.32V](core) / [-3.63~3.63V](IO) •Drain: [0~1.32V](core) / [0~3.63V](IO)
Corner	•TT, FF, SS, FS, SF

The contents of 0.13 um SOI model library

Model QA

- **All corner of model have correct trend, without warning and error. We have an detailed QA report of 0.13 um SOI Model.**

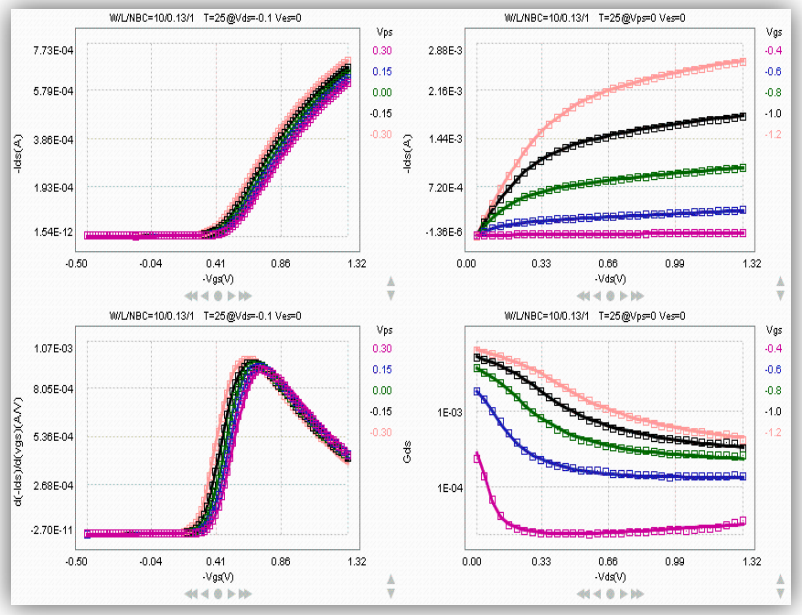
Model Target：

Accuracy：⊿Vtlin<5mV，⊿Idsat<2%

Physical：Cover most physical effects（FBE/SHE）

Scalable：Model QA pass from Wmax/Lmax to Wmin/Lmin

Convergence：We have successfully simulated ring oscillator



Device	ΔVtlin	ΔIdlin	ΔIdsat
Target	<5mV	<3%	<3%
TB Core	<5mV	<1%	<1%
FB Core	<5mV	<1%	<1%
TB IO	<5mV	<2%	<2%
FB IO	<5mV	<2%	<2%

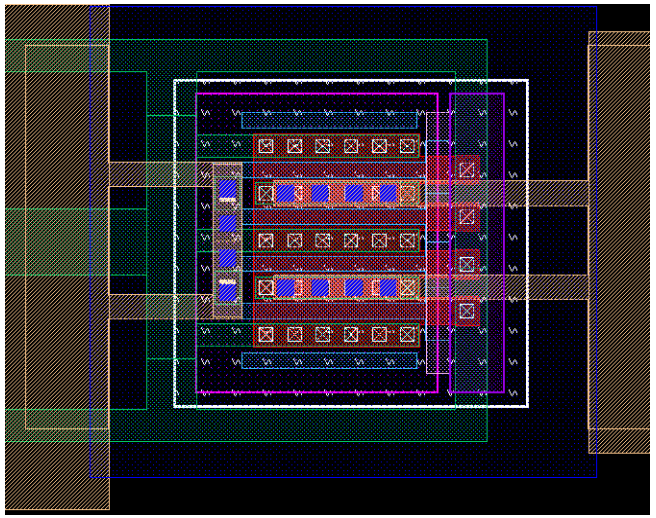
Ring Oscillator Results

- We have designed ring oscillator for the verification of SOI Model. As shown in the table, the simulation error is less than 10%.

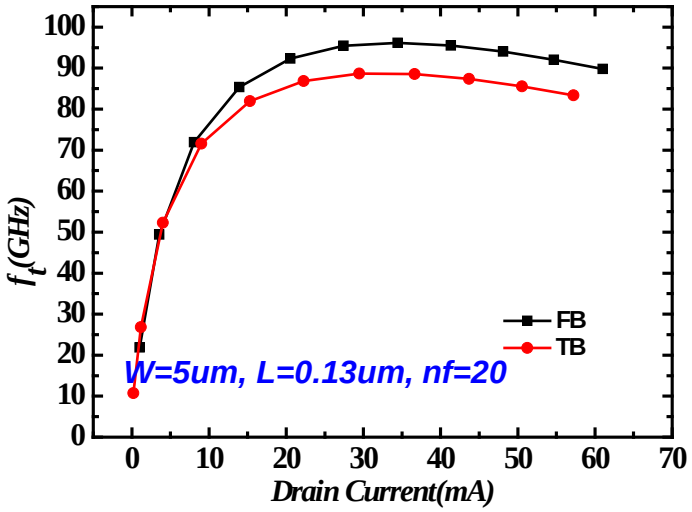
Ring Oscillator	Wp/Wn	Lp/Ln	FO	FF	Simulation Delay	Test Delay	Accuracy
1.2V_FB_INV	3/2	0.13/0.13	1	6	19.3	18.9	1.9%
	2/1	0.13/0.13	1	6	21.7	21.8	-0.8%
	3/2	0.13/0.13	3	5	40.4	38.7	4.5%
1.2V_TB_INV	3/2	0.13/0.13	1	6	25.6	25.1	2.1%
	2/1	0.13/0.13	1	6	29.2	29.7	-1.8%
	3/2	0.13/0.13	3	5	52.8	50.2	5.3%
3.3V_FB_INV	3/2	0.30/0.35	1	6	41.1	39.9	3.1%
	2/1	0.30/0.35	1	6	45.2	44	2.8%
	3/2	0.30/0.35	3	5	88.8	86.3	2.8%
3.3V_TB_INV	3/2	0.30/0.35	1	6	41.9	44	-4.6%
	2/1	0.30/0.35	1	6	47.3	49.8	-4.9%
	3/2	0.30/0.35	3	5	95.4	99.5	-4.1%

RF MOSFET

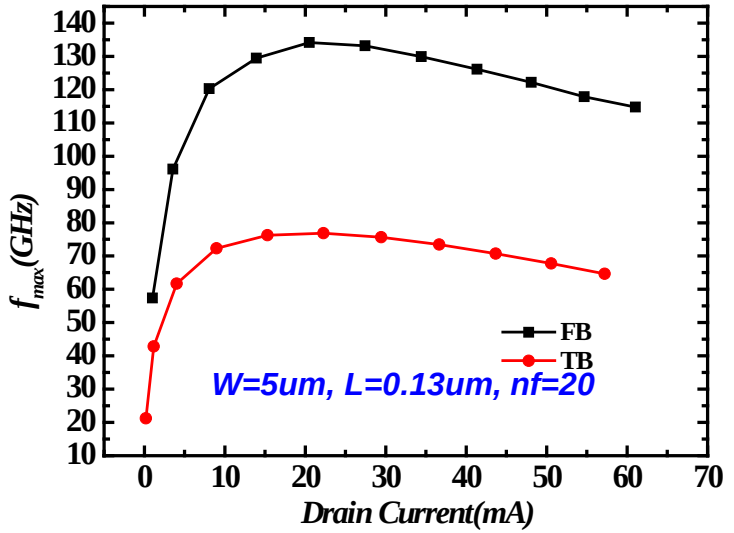
- We have designed RF test structure of SOI MOSFETs.
- The peak cutoff frequency (f_T) and maximum oscillation frequency (f_{MAX}) of TB Ncore are 87 and 75 GHz.



- ✓ Core：FB Ncore, FB Pcore,
  TB Ncore, TB Pcore;
- ✓ IO: FB NIO, FB PIO, TB NIO, TB PIO;
- ✓ Finger：4，20，60，120；



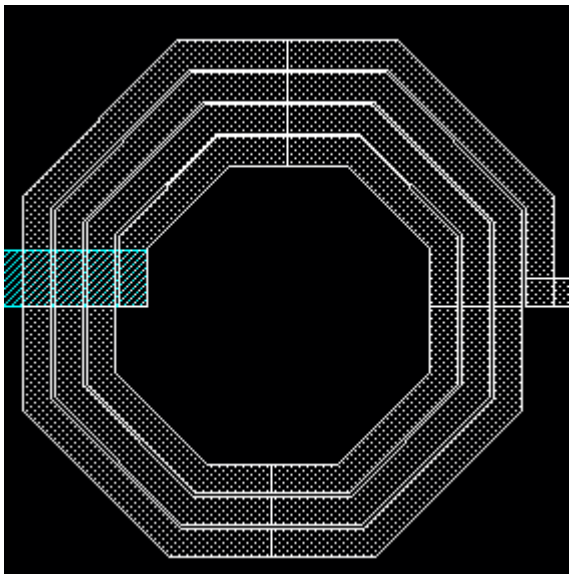
f_T characteristics of SOI Ncore device

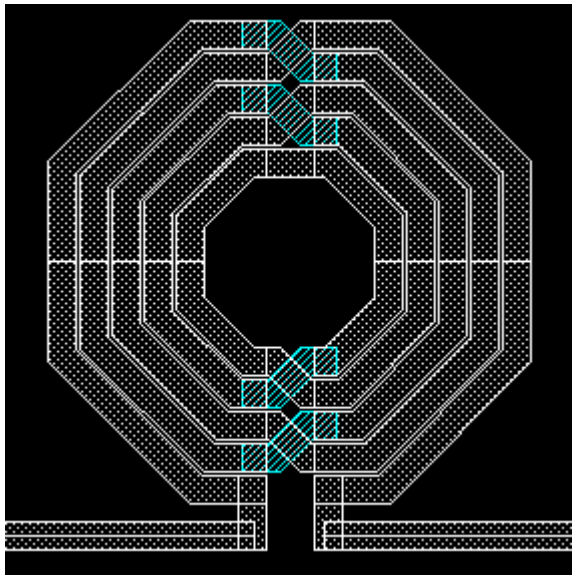


f_{MAX} characteristics of SOI Ncore device

Inductor

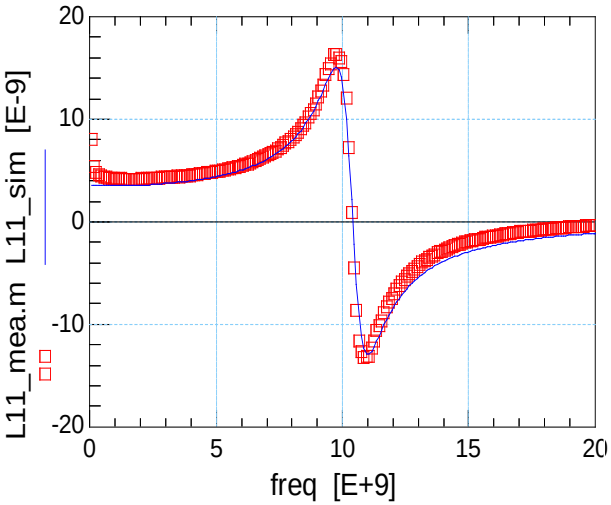
- We have designed Inductor test structure.
- The peak of Q factor is 16 in standard inductor with N=5.5, W=9um, S=2um, D=255um.

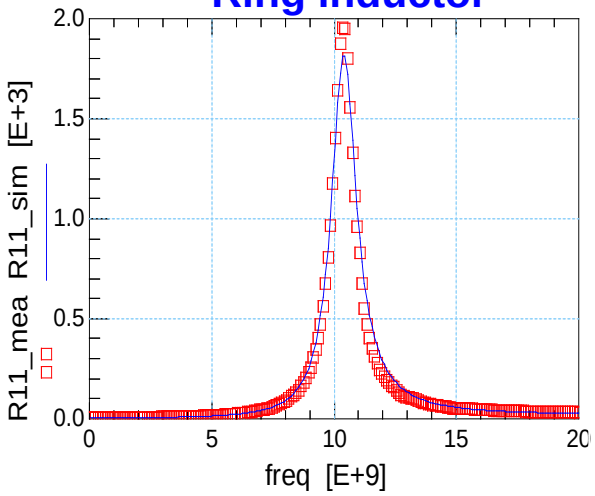


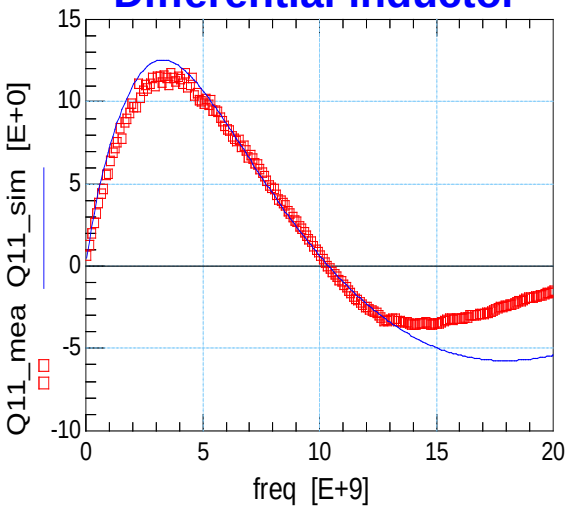


Ring inductor

Differential inductor





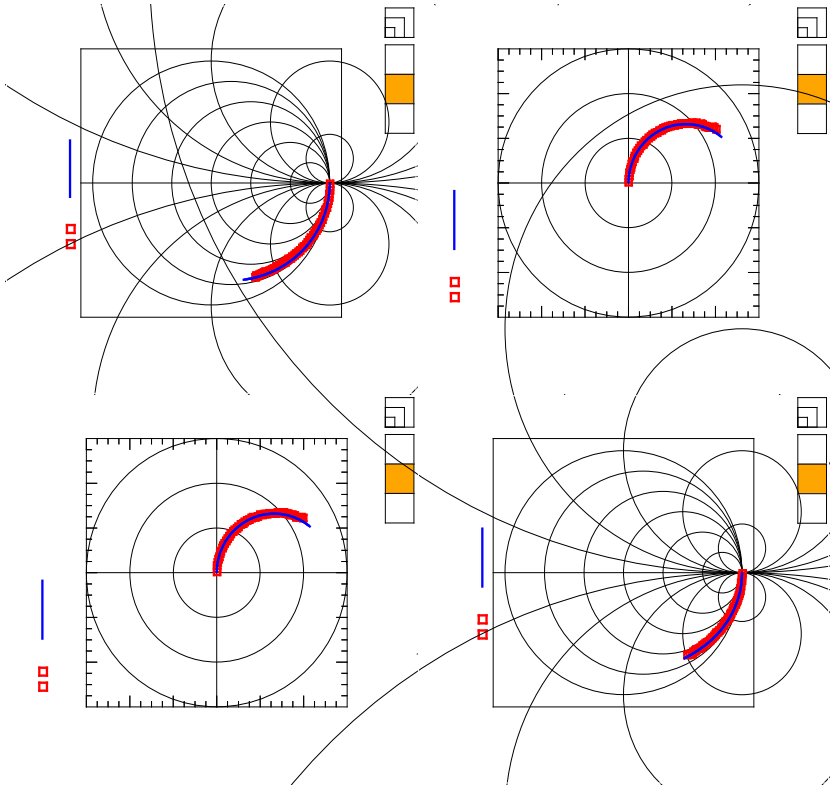


RF characteristics of 0.13 um SOI standard Inductor with N=5.5, W=9um, S=2um, D=255um.

RF Device Model

- We have extracted RF Device Model for 0.13 um SOI Technology.

Device	• MOS（TB, HB）, Inductor, Resistor, • Varactor, MIM, MOM
Level	• 70 (BSIM4SOI)
Effects	• FBE/GIFBE, SHE, Gate-leakage, GIDL
Geometry	• Core: L[0.13~0.75um], W[1.5~8um] • IO: L[0.35~0.75um], W[1.5~8um]
Temp.	• -55~125°C
Voltage	•Gate: [-1.32~1.32V](core) / [-3.63~3.63V](IO) •Drain: [0~1.32V](core) /[0~3.63V](IO)
Corner	• TT, FF, SS, FS, SF



Simulation result of RF NMOS

Application of SOI Model

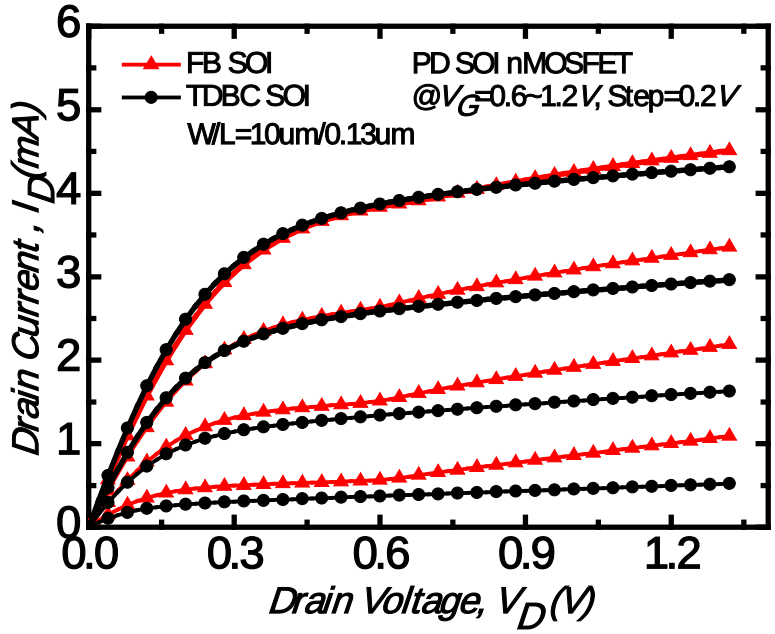
- 0.13 um SOI model was applied to SOI Library and ASIC circuit design.
- The model has become an important part of 0.13 um SOI technology platform, which provides a powerful guarantee for the SOI high reliability circuit design.

ASIC Chip Verification

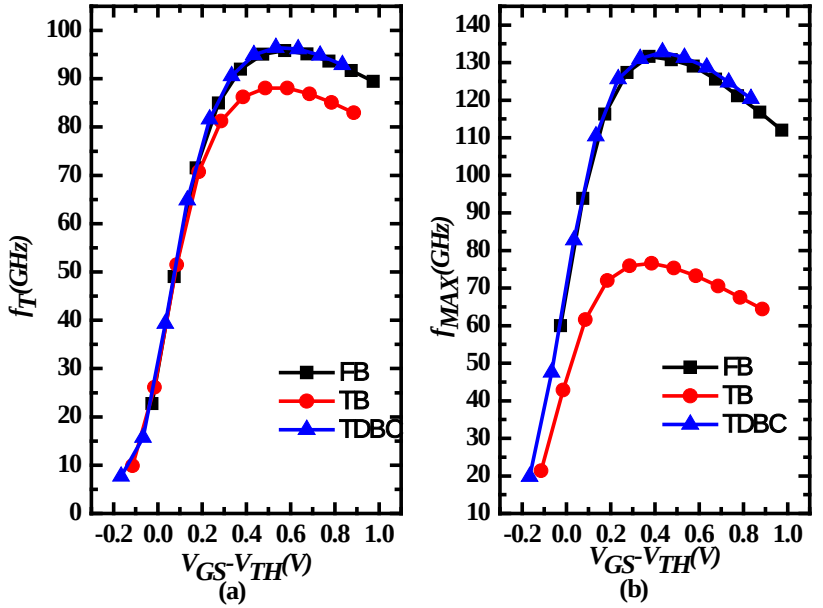
Chip Parameters	Performance
Working Frequency	50Mhz
Chip Scale	> 2M gates
Chip Area	8mm x 9mm
Dynamic Power	250mA

Novel Body Contact Structure

- TDBC SOI devices without floating-body effects are successfully demonstrated, which represent an improvement of 10% for the f_T and of 90% for the f_{MAX} compared with conventional T-gate body-contact devices.



Kink are perfectly suppressed in TDBC devices

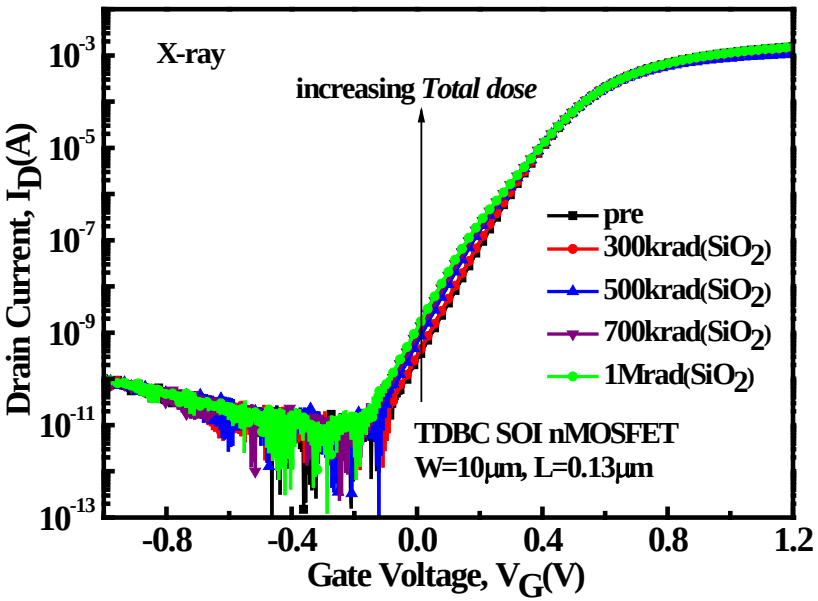


Superior RF performance of TDBC devices

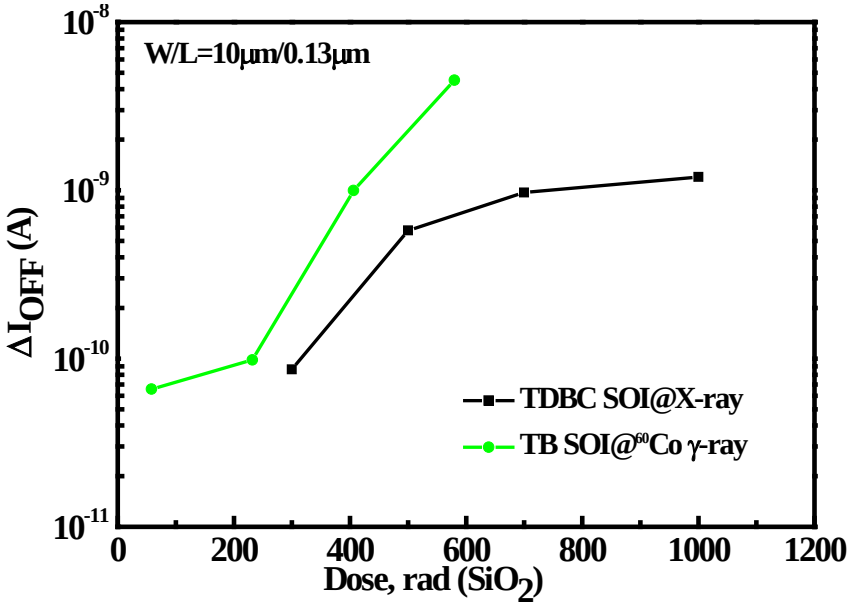
- *Jing Chen, Jiexin Luo et al., IEEE Electron Device Letters, 32(10), 1346, 2011*
- *Jiexin Luo, Jing Chen et al., IEEE Transactions on Electron Devices, 59(1), 101, 2012*
- *Kai Lu, Jing Chen et al., IEEE Electron Device Letters, 35(1), 15, 2014*

Total Dose Effects of TDBC Device

- **TDBC contact makes these SOI transistors strongly resistant to back channel radiation effects.**



Total Dose Effects of TDBC SOI Ncore



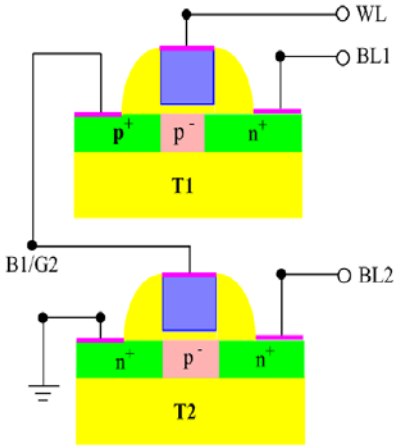
Total Dose Effects of TDBC and TB SOI

Cooperated with E. X. Zhang and D. M. Fleetwood, Vanderbilt University, USA

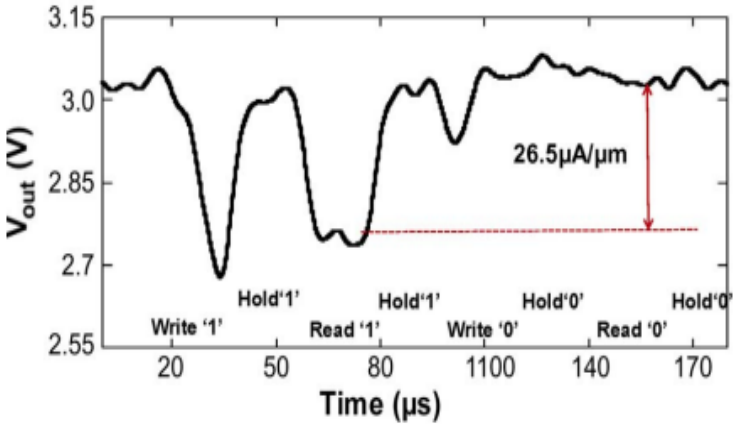
Jiexin Luo, Jing Chen et al., IEEE Transaction on Nuclear Science, 61(6), 11, 2014

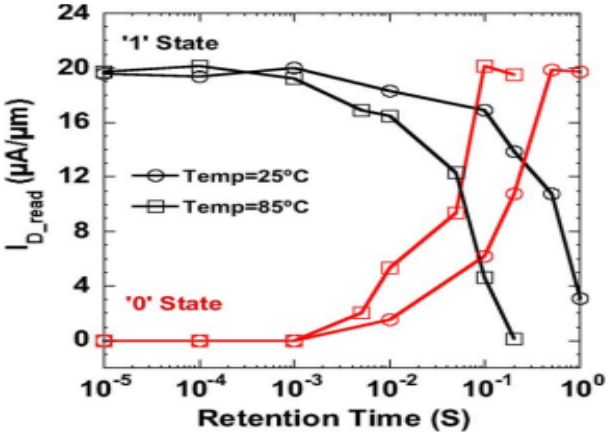
Floating-Body/Gate Cell

- We have experimentally demonstrated a novel capacitorless DRAM cell named FBGC on planar SOI CMOS technology .
- FBGC has large noise margin and long retention time, also shows excellent endurance nondestructive read characteristics and low-power operation.



Schematic structure of FBGC





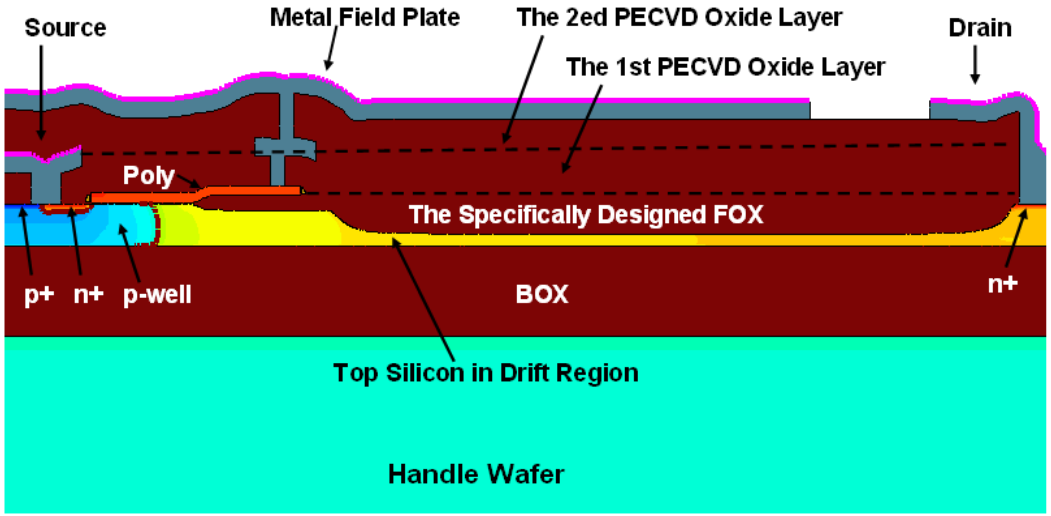
FBGC has large noise margin (26.5uA/um) and long retention time (560ms)

Cooperated with Zhichao Lu and Jerry G. Fossum, University of Florida, USA

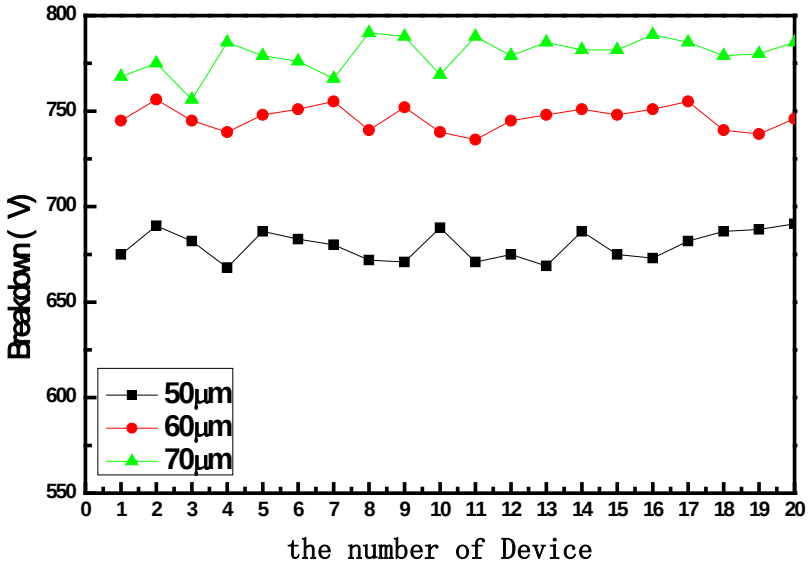
Qingqing Wu, Jing Chen et al., IEEE Electron Device Letters, 33 (6), 743, 2012

SOI LDMOS device

- **SOI LDMOS devices was successfully fabricated, the off-state breakdown voltage can reached to 750V.**



Schematic structure of SOI LDMOS



The off-state breakdown voltage of SOI LDMOS

Zhongjian Wang, Xinhong Cheng et al., Microelectronic Engineering, 91, 102, 2012

Silicon Photonics

- It is expected to find applications in designing compact optical components to achieve the on-chip beam steering in photonic circuits.

Physical Review Letters (2011.5.20), Editor's Suggestion

Physics
spotlighting exceptional research

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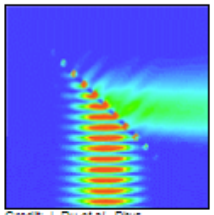
APS » Journals » Physics » Synopses » Sharp turn ahead for light beams

Sharp turn ahead for light beams



Credit: J. Du et al., Phys. Rev. Lett. (2011)

Optical Beam Steering Based on the Symmetry of Resonant Modes of Nanoparticles

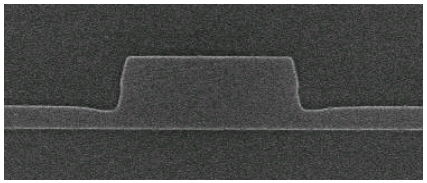
Junjie Du, Zhifang Lin, S. T. Chui, Wanli Lu, Hao Li, Aimin Wu, Zhen Sheng, Jian Zi, Xi Wang, Shichang Zou, and Fuwan Gan

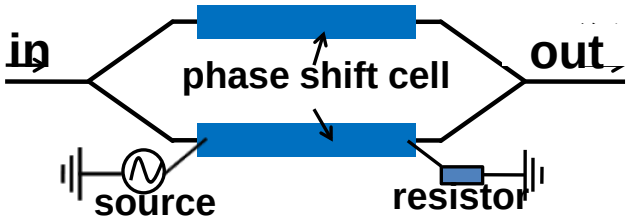
Phys. Rev. Lett. **106**, 203903 (Published May 20, 2011)

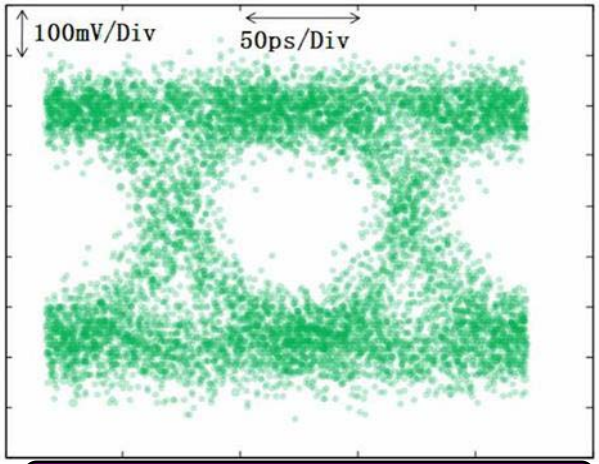
Optics

Over the last decade, the field of optics has been turned on its head by artificial materials that bend light in ways that no natural material can. In a new development, theorists have shown that a carefully designed array of tiny rods can deflect a light beam at a sharp angle. As explained in *Physical Review Letters*, this unique light response is due to interference in

✓APS special reported



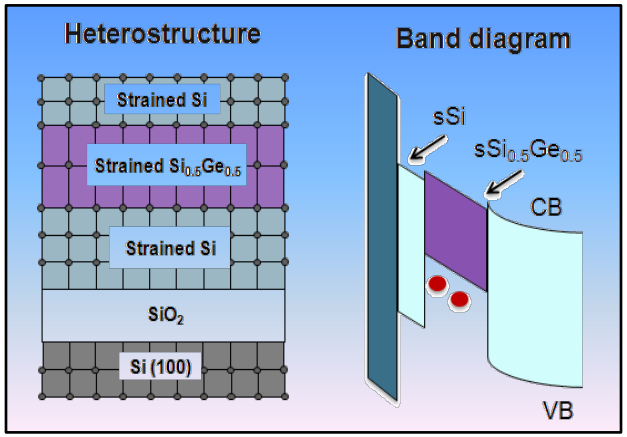


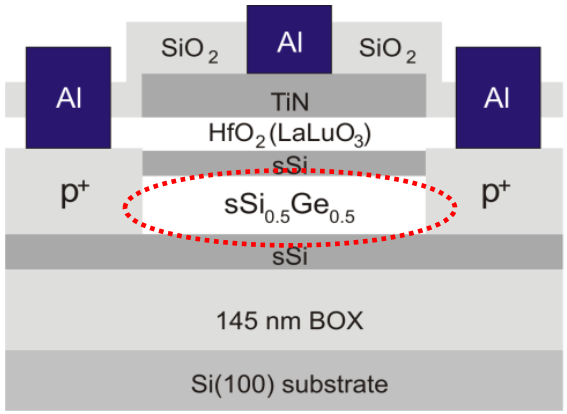


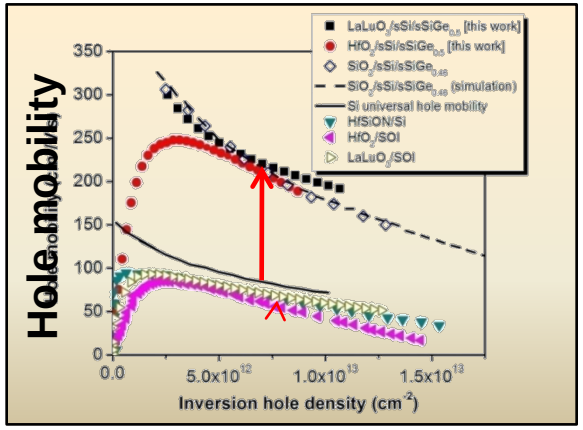
✓10Gbps transfer speed

High-K SiGe/SOI quantum well

- **Epitaxial growth of strain silicon substrates was achieved via an Al interlayer mediated epitaxial. The hole mobility is 2.5X larger than Bulk channel.**







✓sSi/sSiGe/sSOI substrate

✓Carries are confined in sSiGe

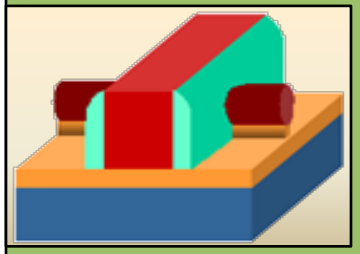
✓2.5X larger than Bulk channel

Cooperated with Juelich Research Center, Germany

- *Bo Zhang et al., Applied Physics Letters, 98, 252101 (2011)*
- *Bo Zhang et al., Solid-State Electronics, 62(1), 185, 2011*

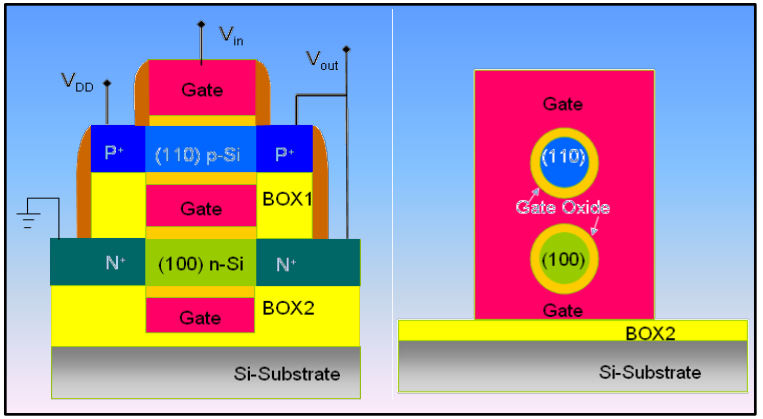
Nanowire on SOI

- **SSRM has been used to characterize doping in silicon nanowire for the first time. The GAAC FinFET appears to be a good potential candidate for scaling down to sub-10 nm sizes.**



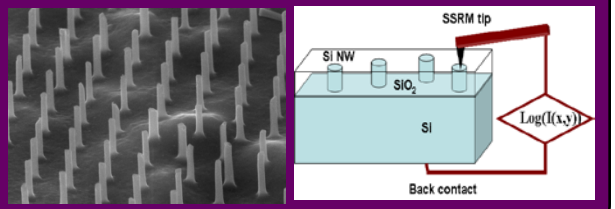
✓Perfect structure with gate all-rounded

✓Easy to implement on SOI



✓Nanowire on Hybrid orientation SOI

SSRM (Scanning Spreading Resistance Microscopy)



Cooperated with Forschungszentrum Dresden-Rossendorf, Germany

- *Xiao Deyuan et al., Journal of Semiconductors, 30(1), 2009*
- *Xin Ou et al., Advanced Materials, 22(36), 4020, 2010*
- *Xin Ou et al., Nano Letters, 10(1), 171, 2010*

Outline

- Introduction of SOI Group
- Research results
  - ✓ DC Device Model
  - ✓ RF Device Model
  - ✓ Research of SOI Device
  - ✓ Fruits of international cooperation
- Summary

Summary

SOI Group	• The leading SOI research teams in China are actively driving new SOI technology development, help to build up SOI ecosystem.
Device Modeling	• We have extracted a complete Model for 0.13 um SOI technology, which was applied to SOI Library and ASIC circuit design.
Research of SOI Device	• We have designed TDBC SOI device, FBGC Cell, LDMOS, Nanowire, Silicon photonics integrated chip, and so on.
International cooperation	• We have fruits of international cooperation with some famous university in USA and Research Centers in Germany.


Thank you !