



IHP RFIC Interoperable Cryogenic PDK

Anton Datsuk

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IHP – Leibniz-Institut für innovative Mikroelektronik



Leibniz Institute
for high
performance
microelectronics



Goals



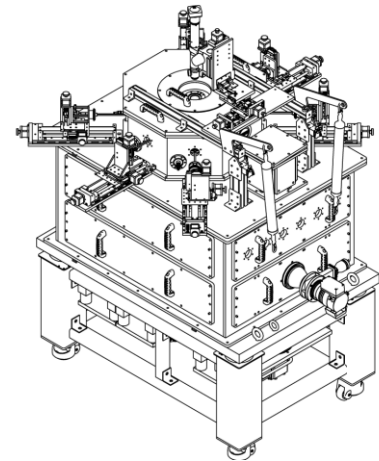
- Modelling and manufacturing of a state-of-the-art IHP SG13 BiCMOS process.
- Development of Cryo-PDK for IC design in CAD tools at 4 K.
- Development of test structures and circuits for Cryo-PDK evaluation.
- Annotate the data from the measurement results of the provided test circuits back PDK to tune the model cards.



Cryogenic Probe Station



- IHP ordered Cryogenic Probe Station, installation end of 2022
 - cost effective, stable, reliable and convenient low temperature semiconductor testing
 - cryogenic wafer-scale testing of devices and circuits
 - DC and RF on wafer measurements at 4 K
- System is still in production and not yet assembled
- Current solution requires constant supply of liquid helium which is inconvenient and expensive.



HBT:

- alpha version model of npn13G2C extracted and embedded into PDK.

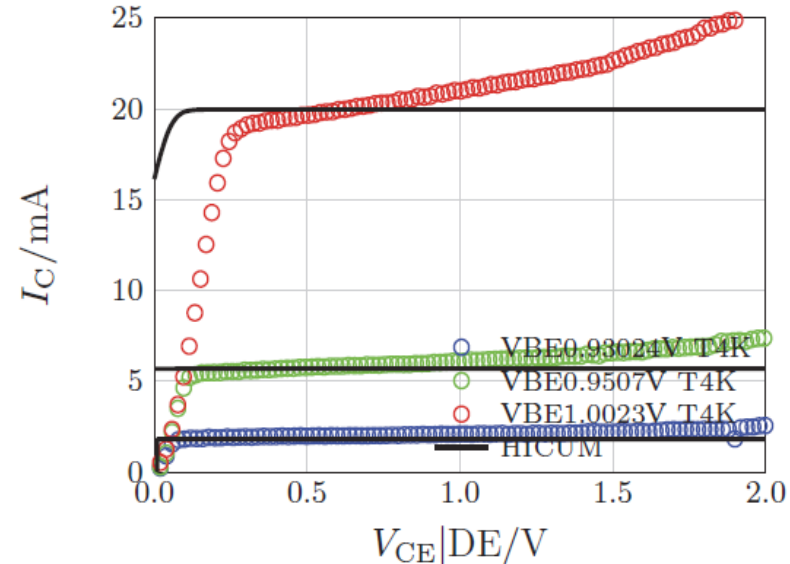
MOS:

- measurements and model extraction of the MOS-devices for various geometry completed and injected into PDK model cards.

Resistors:

- Sheet resistance (SR) at 4K was measured.
- Models for SG13G2 were reused with updated SR.

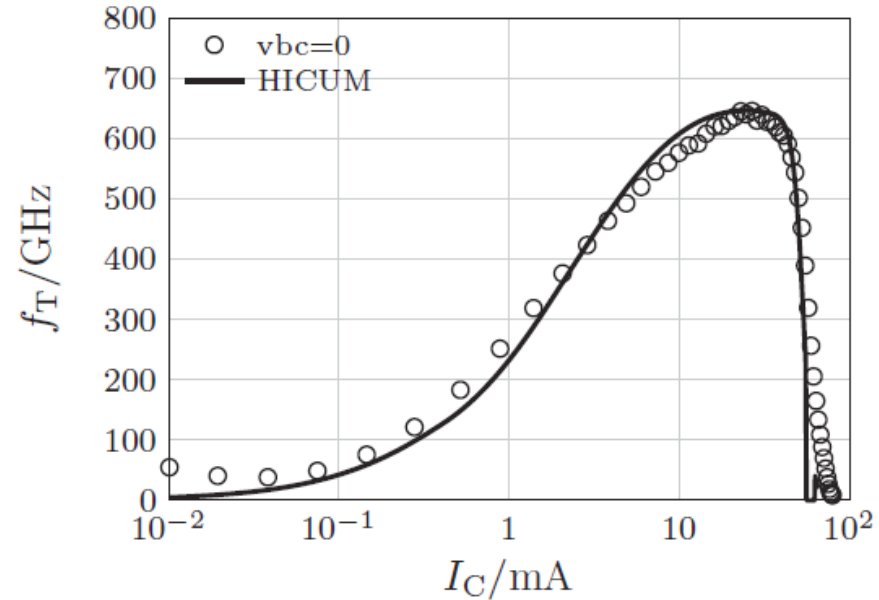
- A new SiGe HBT alpha model for cryogenic temperature range was developed.
- The simulated data show a reasonable agreement with the measured values from 4K.
- HBT models are delivered as encrypted due to security reason.



Cryogenic HBT models – simulation at 10K without self-heating



- Due to convergence issue of HBT alpha model there are limitations:
 - Designer is to set the simulation temperature at 10K.
 - Self-heating is turned off.
- Saturation and break down range are not yet considered.



Cryogenic MOS models



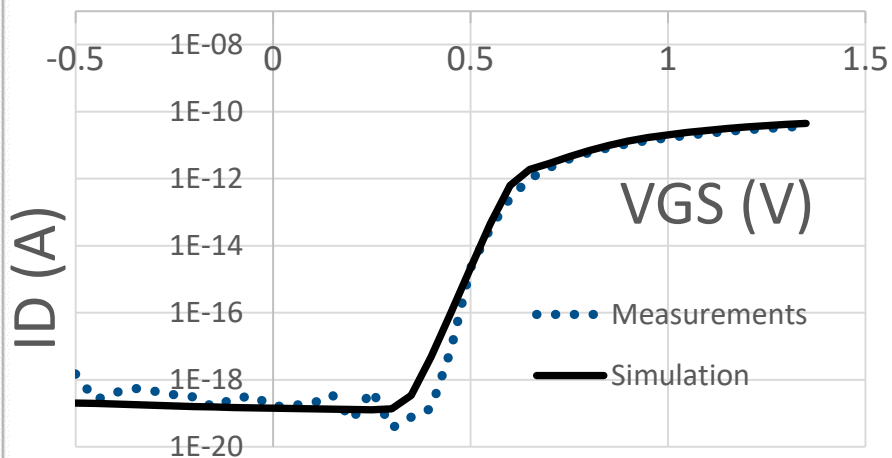
- The provided MOS model cards were extracted in the range 20K...4K.
- Verification performed for different device geometries.
- Worst case deviation is 20% (The goal is to keep it below 10% for all important bias conditions).
- The MOS models still require at least one more iteration to get better fitting with the measurements. Exp. 2023.
- A ring oscillator is being developed using the Cryo PDK to verify the MOS models and it is to be taped out for fabrication. Exp. 2023.

Cryogenic MOS models (Measurements vs Simulation)

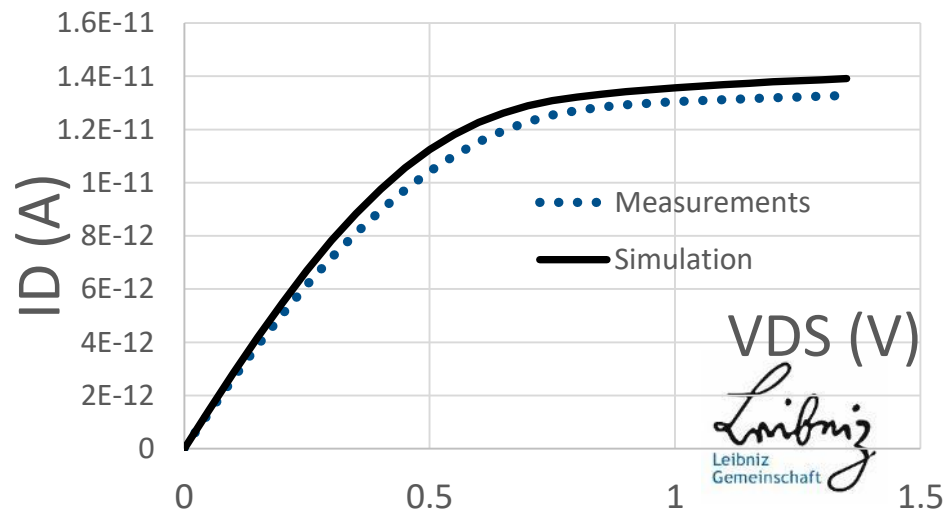


- The extracted MOS model cards were compared vs simulation.
- The models have reasonable agreement with the measurements at 4K.

NMOS W=0.6 μ L=0.13 μ VG=1.2V



NMOS W=10 μ L=5 μ VD=1.35V

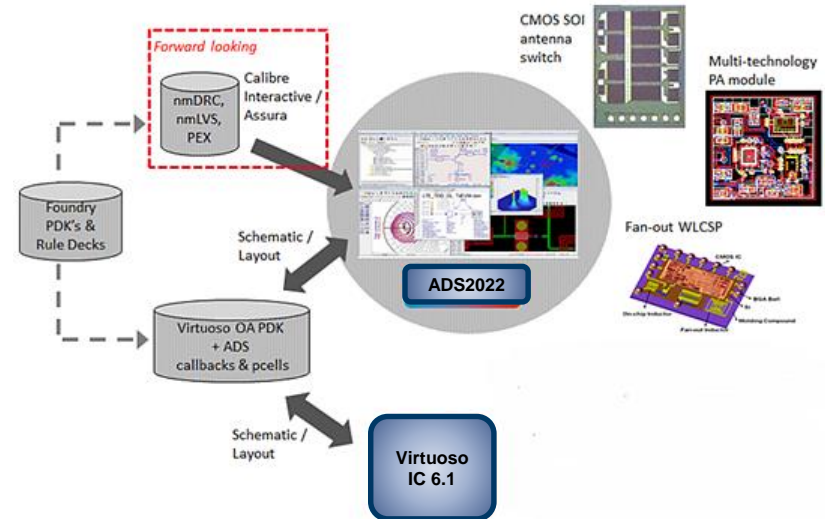
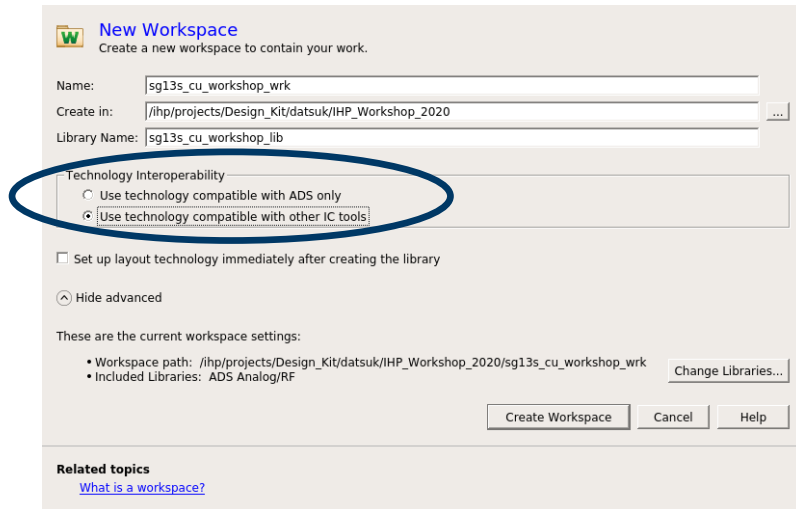


- Sheet resistance (SR) was measured for all resistor types at 4K.
- The resistor model cards were updated in accordance to the new SR-value.
- Temperature coefficients in the model cards were reset to provide reliable simulation results at 4K.
- The updated model cards are temperature independent and compatible with HBT simulation flow.
- The provided model cards have a perfect agreement (simulation vs measurements) at 4K.

RFIC Interoperability



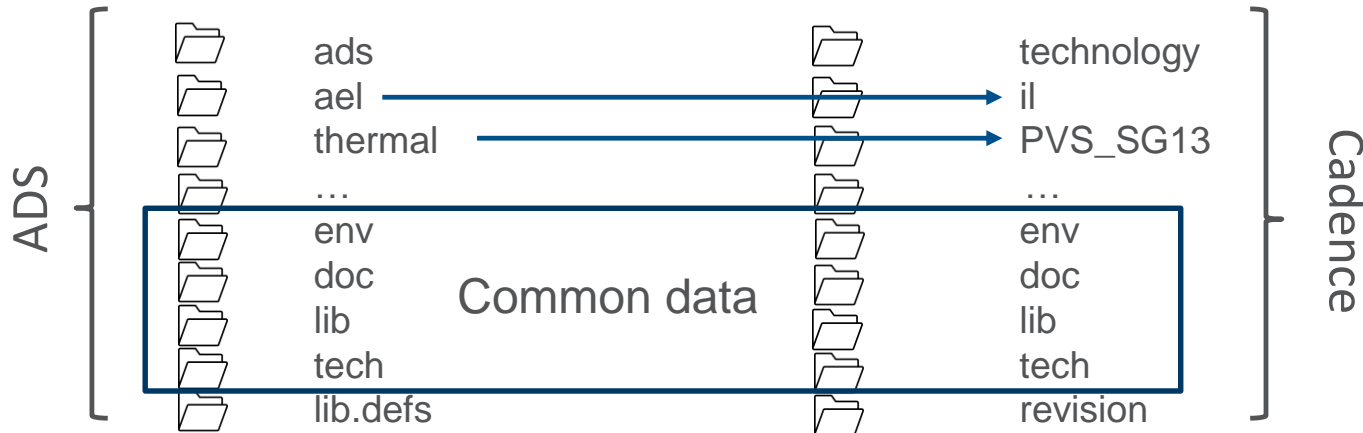
- A single PDK will work with both Keysight ADS and Cadence Virtuoso simultaneously.
- A schematic/symbol/layout view can be used and edited in both Keysight ADS and Cadence Virtuoso.



RFIC Interoperability



- Cadence PDKs provide a complete physical verification and parasitic extraction work flow.
- ADS PDKs allow performing tuning/optimization/yield, viewing simulation results, back-annotating operating points, etc.



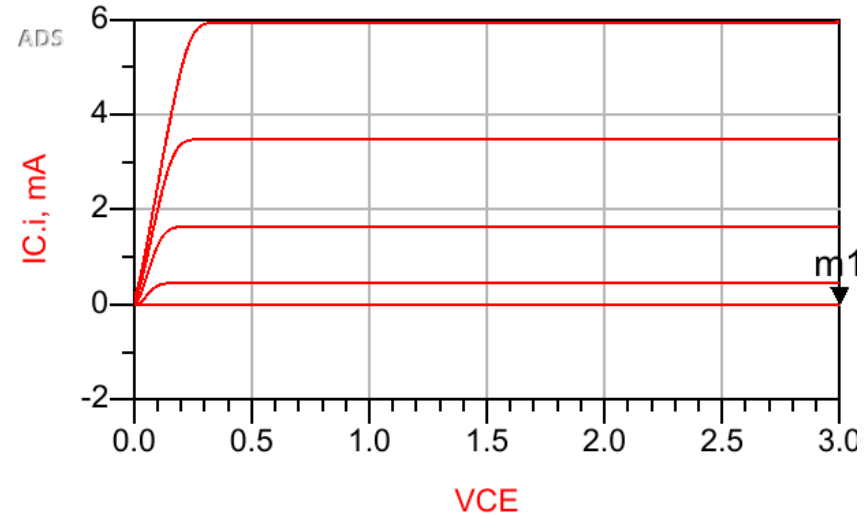
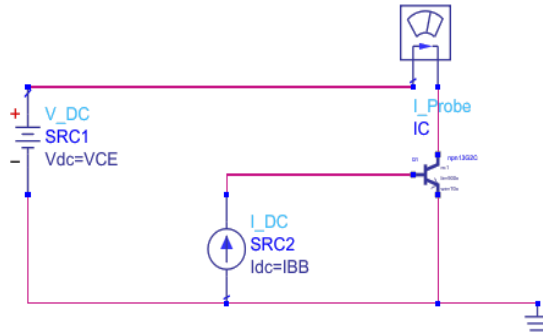
HBT cryo-models embedded into PDK (ADS)



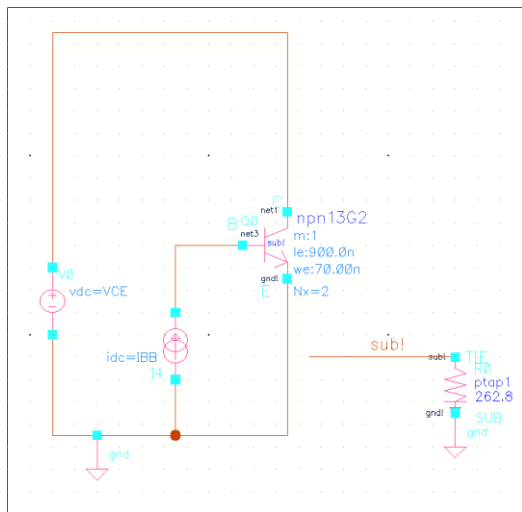
- The first HBT Cryogenic models have been extracted and integrated into PDK.
- Verification of the models is in process.

OPTIONS

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Tnom=25
V_RelTol=
V_AbsTol=
I_RelTol=
I_AbsTol=
GiveAllWarnings=yes
MaxWarnings=10



HBT Cryo-models embedded into PDK (Cadence)



Launch Session Setup Analyses Variables Outputs Simulation Results Tools Calibre Help

-263.0

Design Variables

Name	Value
1 IBB	1
2 VCE	1

Analyses

Type	Enable	Arguments
1 dc	<input checked="" type="checkbox"/>	t 0 3 10m Linear Step Size Start-Stop

Outputs

Name/Signal/Expr	Value	Plot	Save	Save Options
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ads/sim/bjt_sim

spectre0: Model Library Setup

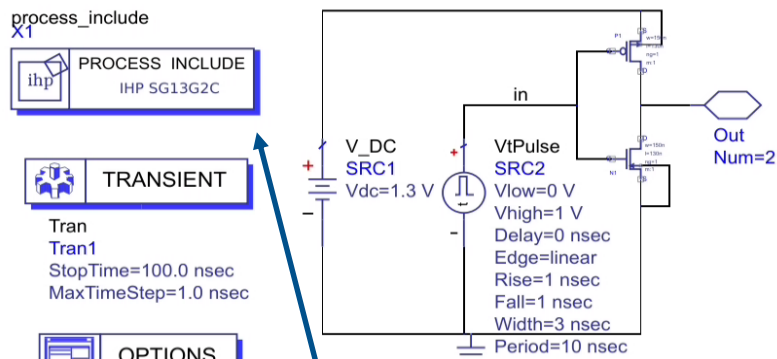
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OK Cancel Apply Help

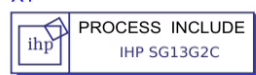
HBT Cryo-models embedded into PDK (Cadence)



- The simulation results for 4K and 10K for MOS transistors does not deviate to much, so they could be used together with **BJT** and RES devices.



process_include
X1



PROCESS INCLUDE
IHP SG13G2C



TRANSIENT

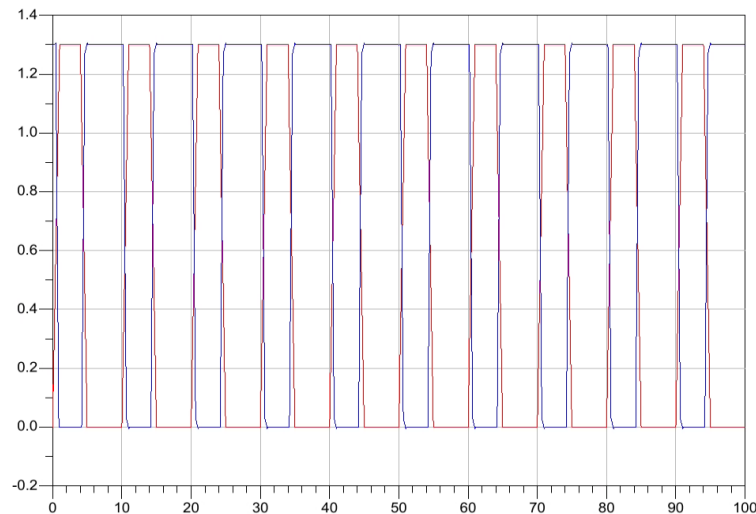
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Tran1
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OPTIONS

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Options1
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Tnom=25
V_RelTol=
V_AbsTol=
I_RelTol=
I_AbsTol=
GiveAllWarnings=yes
MaxWarnings=10

In, Out (V)



Time (nsec)

The corner case simulation
is also provided.



MOS Models are embedded into PDK (ADS)

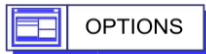


- The simulation results for 4K and 10K for MOS transistors does not deviate to much, so they could be used together with HBT and RES devices.

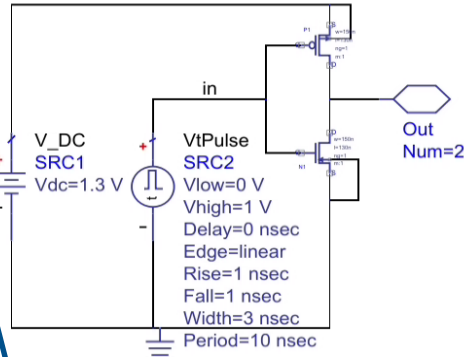
process_include
X1



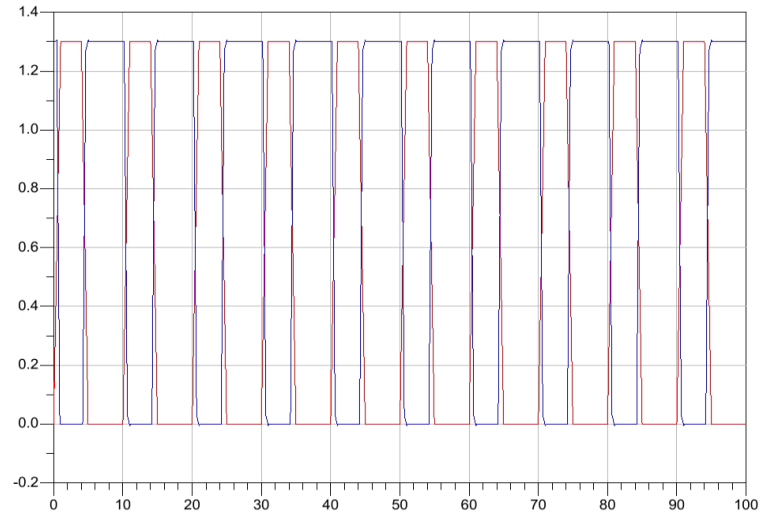
Tran
Tran1
StopTime=100.0 nsec
MaxTimeStep=1.0 nsec



Options
Options1
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Tnom=25
V_RelTol=
V_AbsTol=
I_RelTol=
I_AbsTol=
GiveAllWarnings=yes
MaxWarnings=10



In, Out (V)



The corner case simulation is also provided.

Time (nsec)



Simulation workflow at 10K instead of 4K



- Due to convergence issue at 4K of HBT device the simulation environment temperature is to be set for 10K.
- The HBT simulation results at 10K temperature correspond to 4K measurements.
- Simulation of cryogenic resistors are temperature independent and always correspond to 4K, thus aligned with HBT.
- Simulation of MOS devices at 10K and 4K results in negligible deviation.
- A complete simulation workflow should be setup for 10K.



- ADS and Cadence beta PDK releases (2023).
- Fabrication of ring oscillator to verify HBT models (2023).
- Fabrication of ring oscillator to verify MOS models (2023).
- Extraction of complete resistor models (2023).
- Tuning of PDK models and settings based on the measurement results of the test circuits and re-engineer Pcell profiles for best noise performance (2023).
- Potential measurements of key devices down to 100 milikelvin.

Summary



- The development of PDK is part of the MuniQC-SC (Munich Quantum Computer based on Superconductors) project.
- MuniQC-SC is developing a quantum computer demonstrator based on superconductors ([MUNIQC-SC - Quantentechnologien](#)).
- The Cryo-PDK will be available for the customers end of next year.
- The Cryo-PDK will most like be based on SG13G2 technology process and no additional qualification is required.
- Thanks to Xiaodi Jin from TU Dresden for development of HICUM HBT cryogenic models.





Thank you for your attention!

Anton Datsuk

IHP – Leibniz Institute for High Performance Microelectronics

Im Technologiepark 25

15236 Frankfurt (Oder)

Phone: +49 (0) 335 5625 133

Fax: +49 (0) 335 5625 133

e-mail: datsuk@ihp-microelectronics.com

www.ihp-microelectronics.com



Leibniz Institute
for high
performance
microelectronics

Leibniz
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