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ISSW20:
The International SPAD Sensor Workshop

LFoundry: SPAD, status and perspective

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Outline

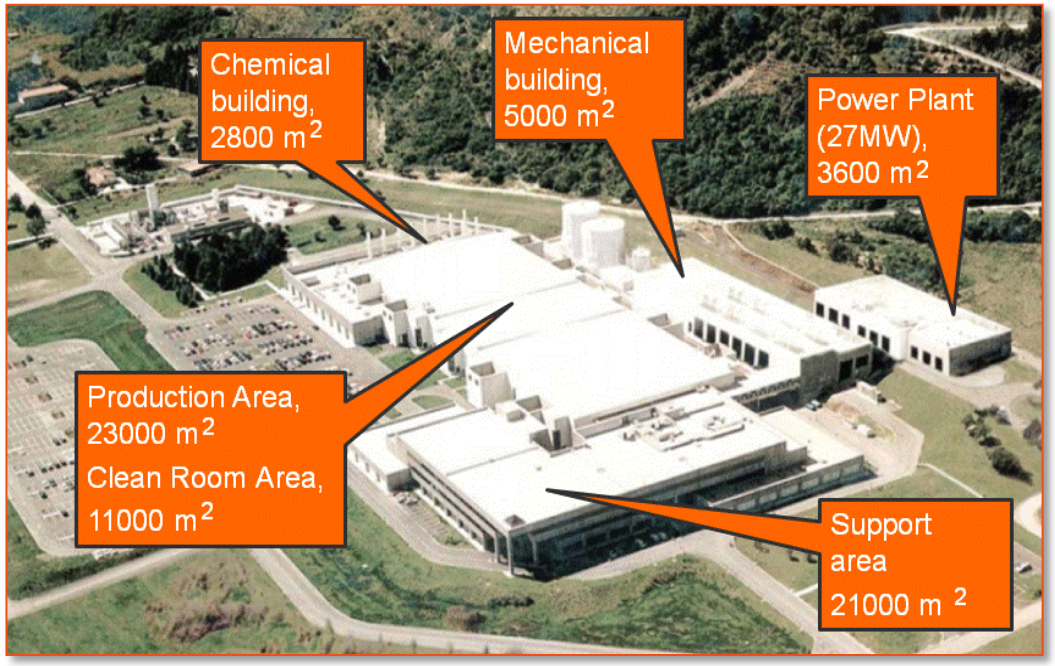
- **About LFoundry**
  - FAB history, products, process capability

- **SIPMs in LFoundry**
  - history and main results

- **SPAD integrated in LFoundry CMOS PDK**
  - history and main results
  - a special case: SUPERTWIN

- **Conclusion**

LFoundry: FAB AT A GLANCE



- **Location:** **Avezzano,** Italy (center of Italy / east of Rome)
- **Founded** May 1989
- **Headcount** ~ 1.500 (>200 R&D and Process & Equip. Engineers)
- **Owner History** 1989 Texas Instruments, DRAM 6” → 8”
  1998 Micron Technology, DRAM 8” → CIS Since 2005
  2013 Lfoundry
  2017 SMIC
  2019 SPARC
- **Products** Optical Sensors (CIS, PD, SiPM), Automotive, Secure, Power, Customer Specific
- **Capacity** 40.000 wafer / month
- **Clean Room** ISO3 (1), 11.000m2
- ISO4/5, 1.000m2
- **Around 800 tools installed**
- **More than 900 gases and chemicals**
- **Certifications** ISO 9001:2008, Quality Management
  ISO 16949:2009, Automotive Quality Management
  OHSAS 18001:1999 Health & Safety Management
  ISO 14001:2003, Environmental Management
  ISO/IEC 15408 Security common criteria (EAL 5+)

Technology at a Glance

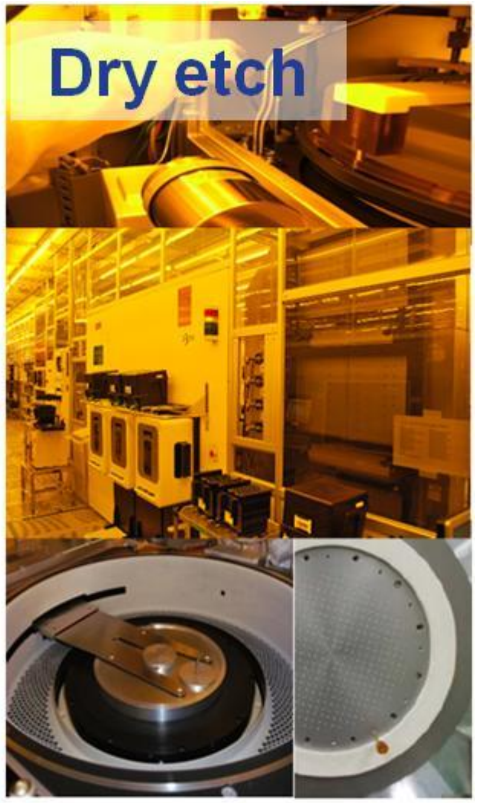
	Key Feature
Avezzano Fab Capability	65nm Smallest Litho Feature 90nm Volume Production Al and Cu Metallization
Basic FOT CMOS Platform	Technology Nodes: 150nm 110nm
Technology Specialization	Optical Sensors (CIS, Discrete PD, SiPM) Analog and Mixed Signal Smart Power (LDMOS)
Special Modules	Back-side Process Wafer Thinning and Stacking Lithographic Stitching

Manufacturing Fab


IMPLANT


RDA


CVD PVD


Dry etch


CMP


WET


DIFFUSION

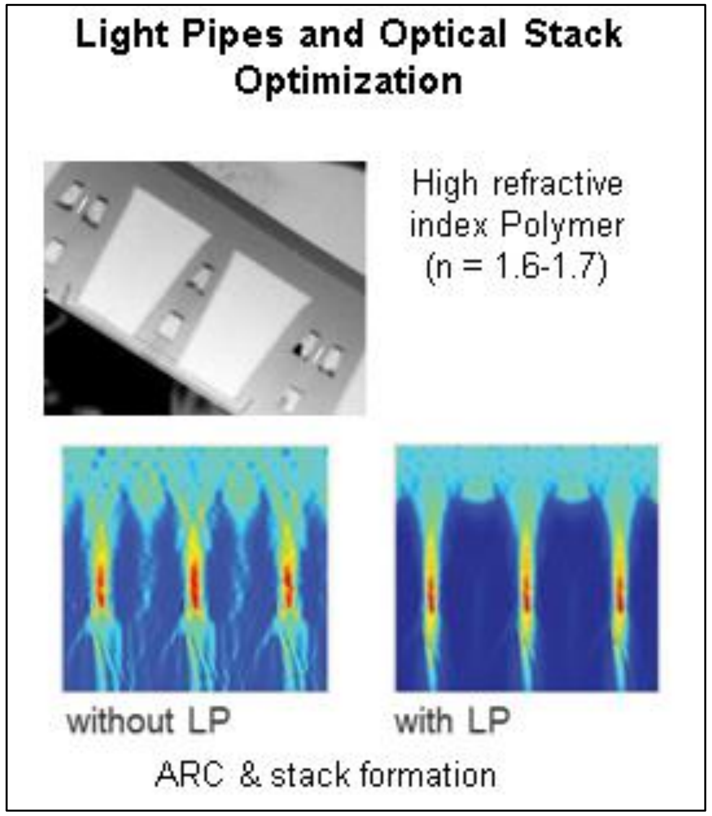

Metrology


Photo

Simplified – descriptive – reference only

Process/Development capability

- Customized wafer type
- Deep Implant with high aspect ratio masks
- Bask Side process capability (see next);
- 1D/2D stitching
- Deep Trench Isolation (1:15)
- Optical stack simulation/optimization
- 2D, 3D TCAD simulation
- Analytic service



TEM/STEM:
TECNAI G2 F30 S-Twin equipped with Lorentz Lens, Bi-prism. EELS and EDX detector. Holography, Tomography

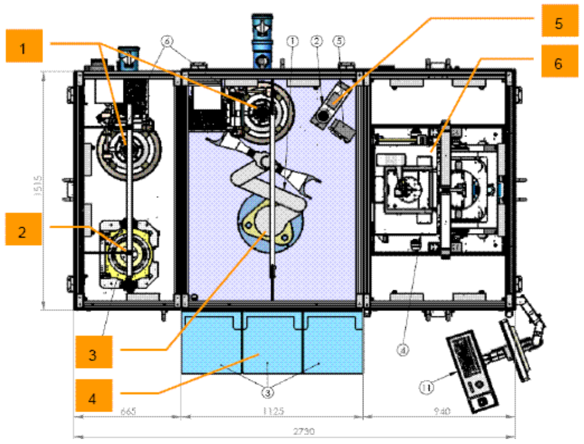
Wafer Level Reliability Equipment

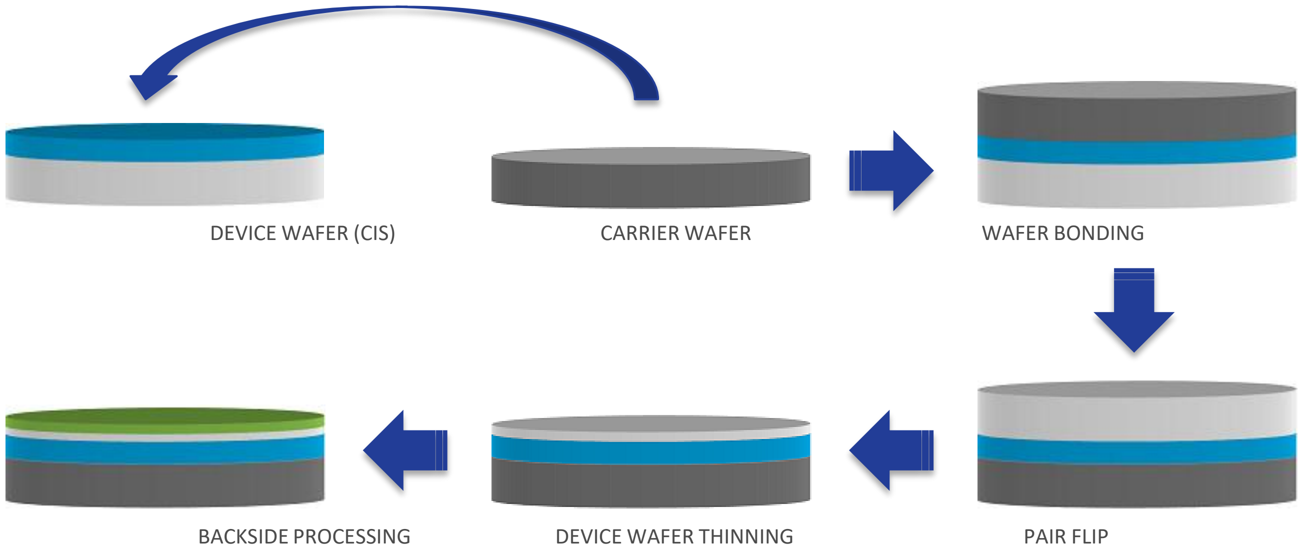
Focus Ion Beams
2 x Dual Beam FEI Strata 235

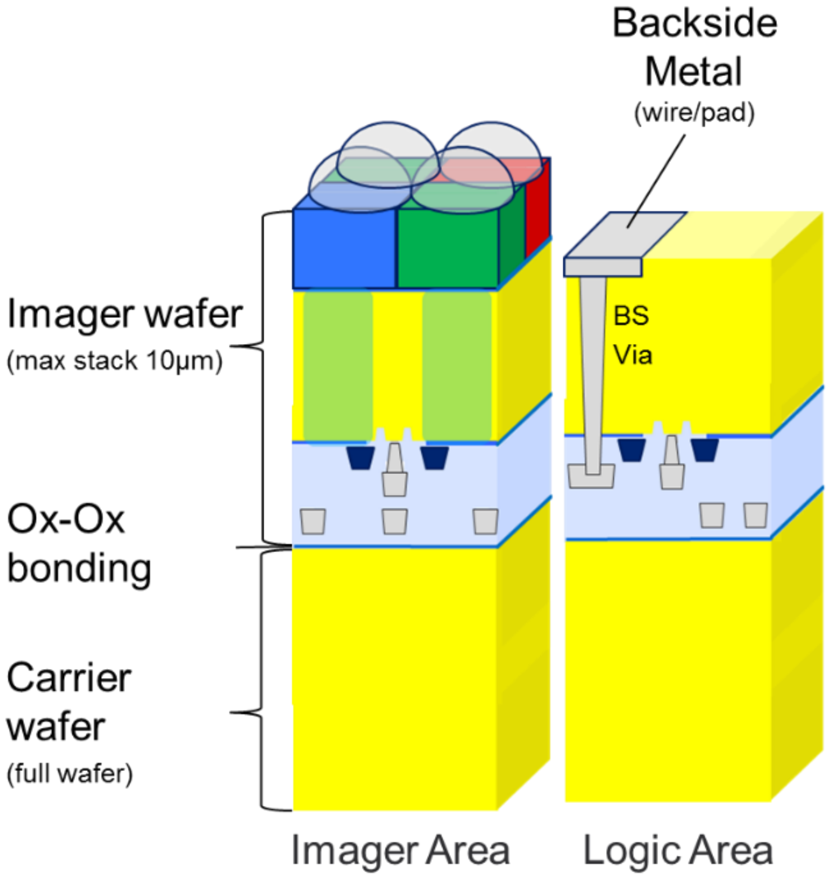
Scanning Electron Microscopes
2 x Hitachi 4700
1 x Hitachi 4800 (with EDX)
2 x FEI Nova-600 Nanosem

BSI Capabilities – an example

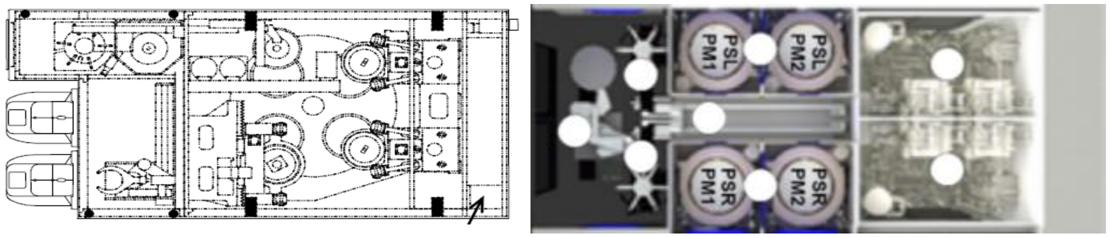
Fusion Bonding







Si Grinder and Si Wet Etch



Laser Anneal

SIPM in LFoundry – brief history

- **LFoundry Fab** especially designed to **ensure low level of contaminant** thus particularly suitable to produce optical sensors (high volume **production of CIS since 2005**)

- In **2016** the **interest for SIPMs** as alternative to PMTs was increasing in the science field as well as in other fields, like biomedical, automotive, etc..

- At the same time **FBK developed** and produced **SIPM**s, but their 6’’ line was not able to support large volume of products.

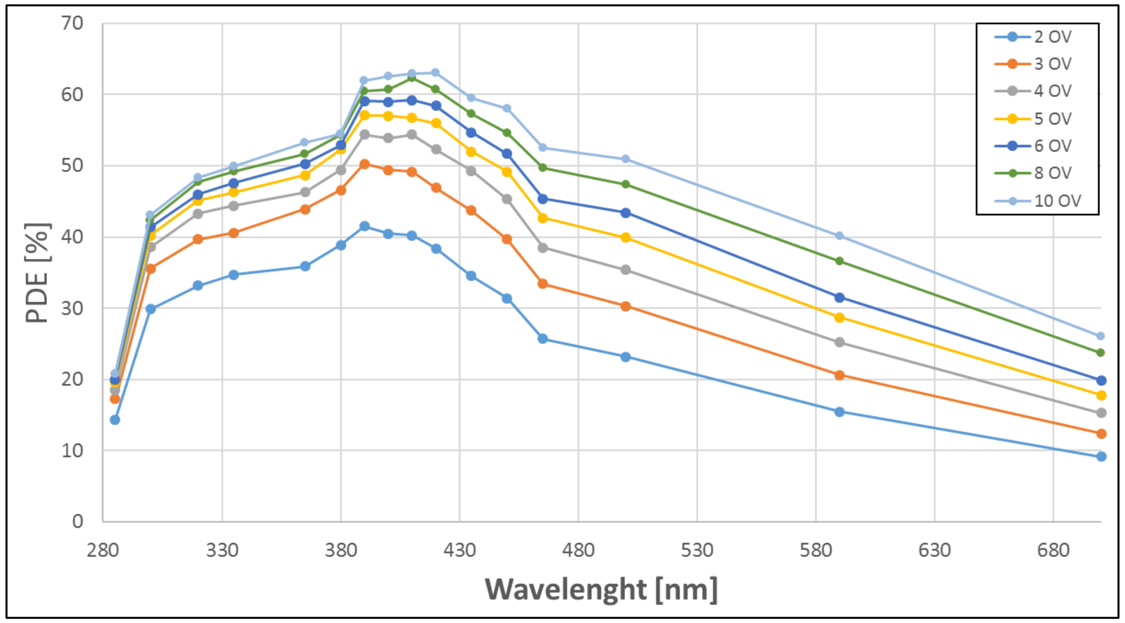
- Based on the above reasons, **LFoundry and FBK agreed that a technology transfer** would have been an opportunity to make the technology available for large quantity orders and for future developments exploiting 8-inches line process capability.

- Starting from 2016 **several SIPMs technology flavours have been transferred** from FBK to LFoundry. NUV-HD (near ultraviolet, high density) SIPM was the first one and after minor adjustments, the **results were found to be aligned to FBK and robust** enough (in terms of reproducibly, process variability) to be produced in large volumes.

- A snapshot of the main characteristics is shown in the next slides

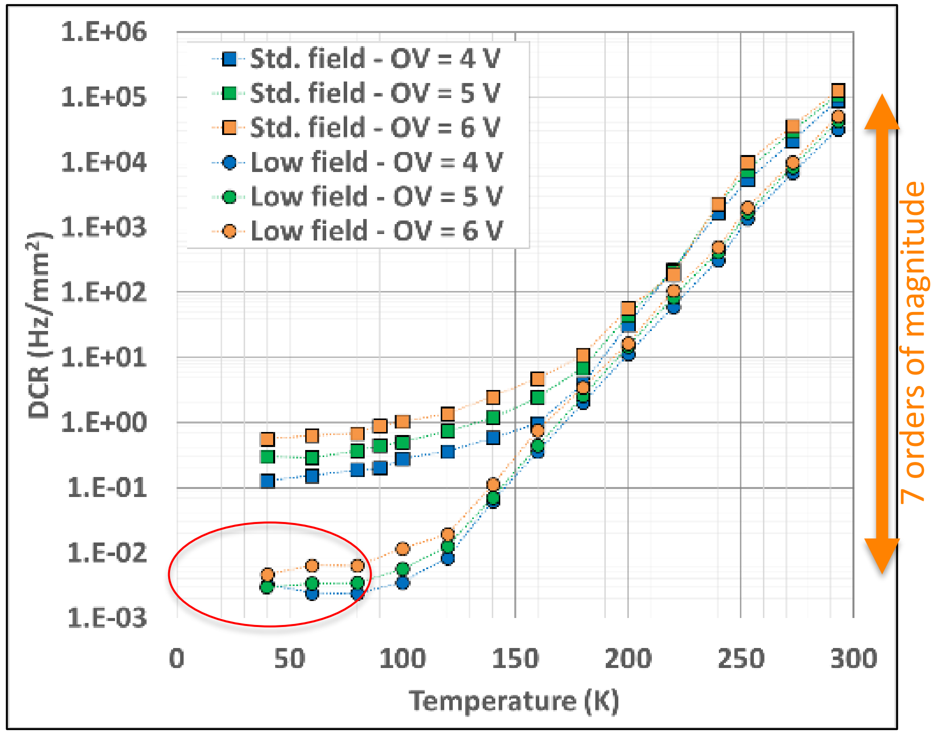
Analog SiPM: NUV-HD / NUV-HD cryo

Parameter	NUV-HD @ 25C	NUV-HD-Cryo @ 25C
Cell Size	15 - 40 µm	15 - 40 µm
Fill Factor	55% - 85%	55% - 85%
Breakdown Voltage	26.5 V	32.5 V
BV Temp Coefficient	28 mV/ºC	34 mV/ºC
PDE (420nm) (5 Vex)	**> 55%**	**> 50%**
Gain	> 10^6	> 10^6
Peak PDE λ	410 nm	410 nm
DCR (20°C, 5Vex)	< 150 kHz/mm2	< 150 kHz/mm2
DiCT	20%	20%
DeCT + AP	2%	2%
SPTR (FWHM)	~ 20ps (single cell)	~ 20ps (single cell)



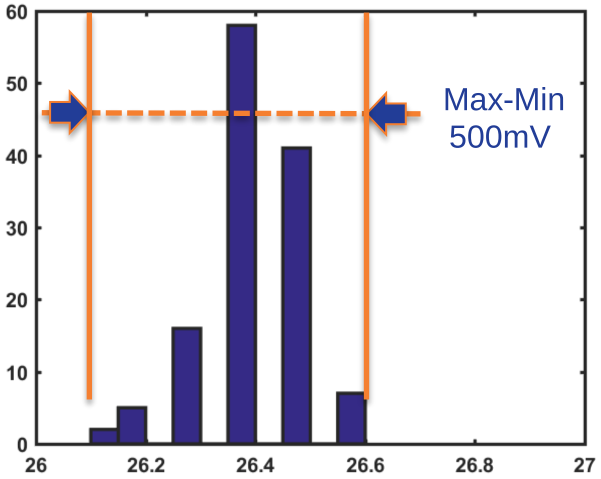
FBK SiPM techn. @ LF manufacturing line

Low Field version enables very low DCR at cryogenic temperatures



Band to band tunnelling probability (main component at low temperature) reduced on low field flavour

Breakdown Voltage Uniformity
on ~2000 dies

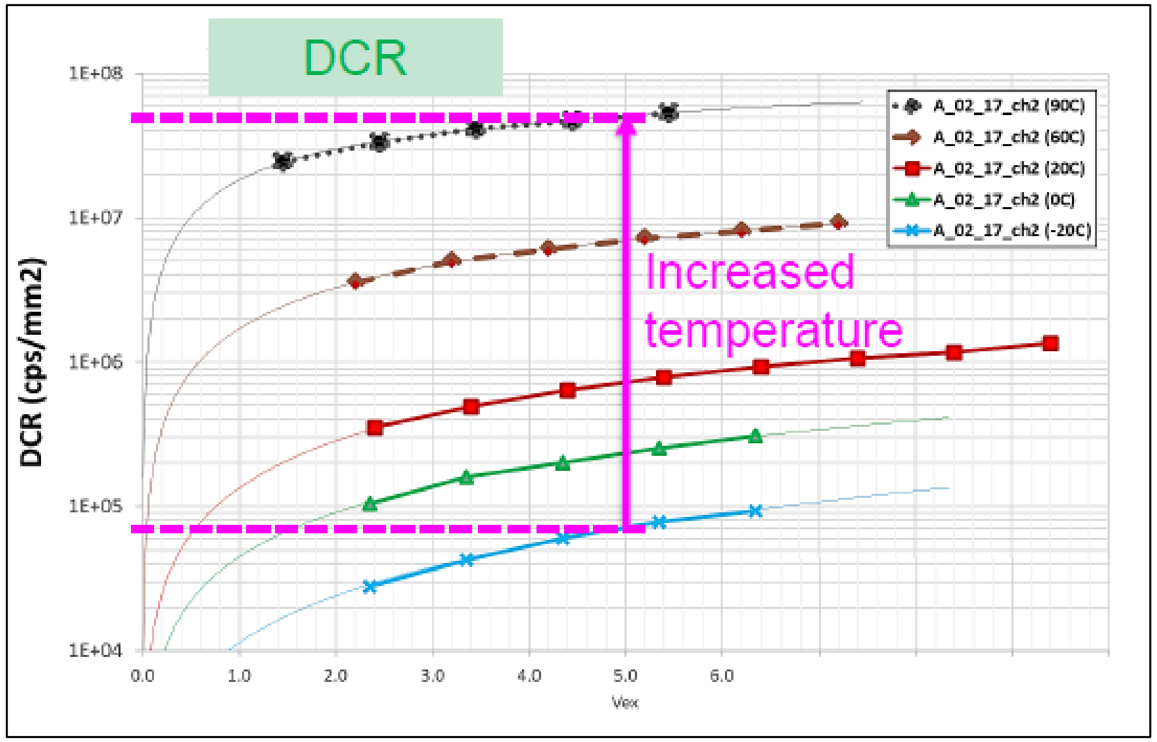


	N UV-HD	NUV-HD Cryo
BV (V)	26.51	32.53
St. Dev. (V)	0.071	0.075
N	> 200000	>20000

Analog SiPM: NIR-HD Technology

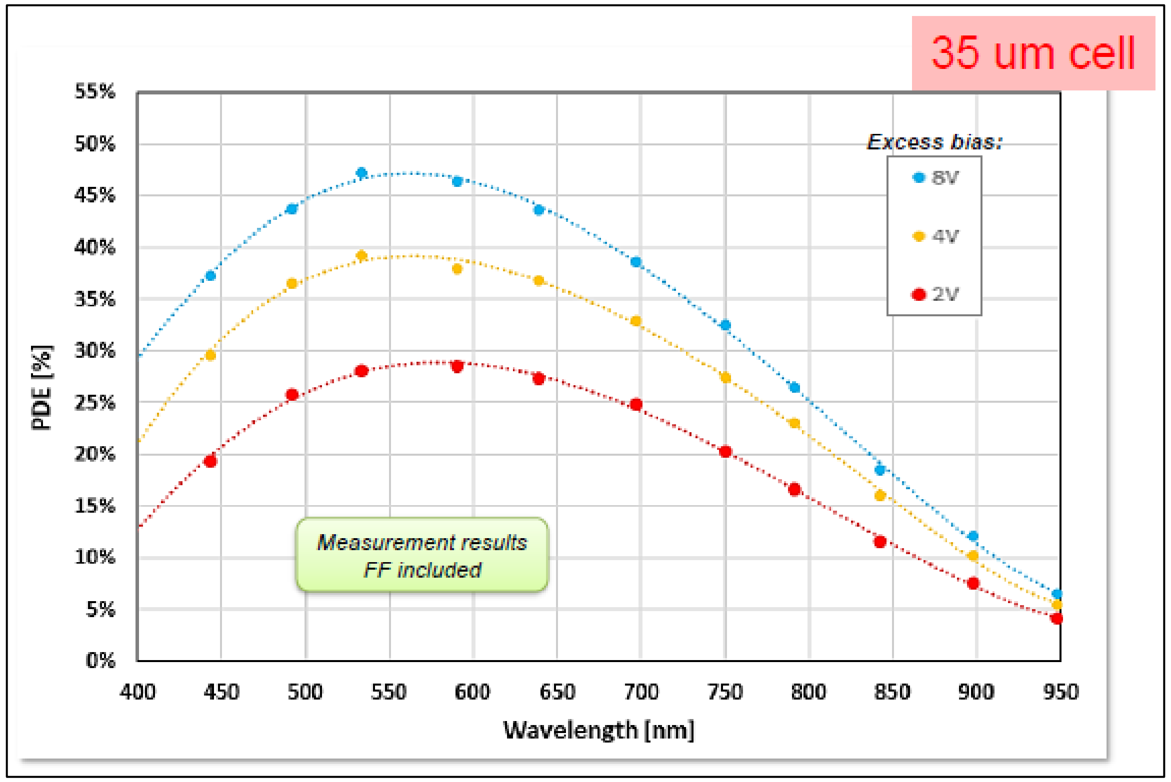
Parameter	Value @ Room T
Cell Size	25 - 35 µm
Fill Factor	75% – 85 %
Breakdown Voltage	27.8 V
BV Temp Coefficient	*** 28mV/ºC**
PDE (850nm, 5Vex)	13-16%
Gain	> 10^6
Peak PDE λ	545 nm
DCR (20°C, 5Vex)	< 800 KHz/mm2
DiCT	14% - 22%
DeCT + AP	12% - 18%
SPTR (FWHM)	~ 60ps (single cell)

*good results for an high depleted region cell

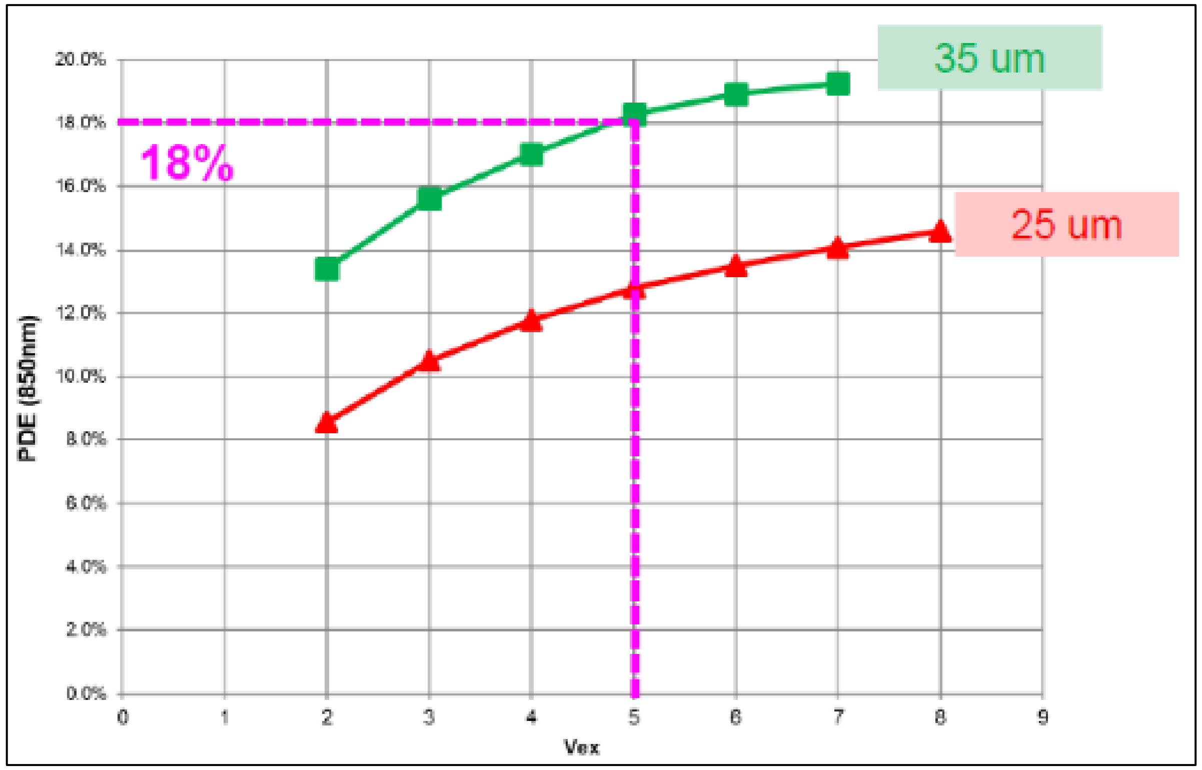


Data from FBK silicon
Technology implemented in LF line

PDE vs Wavelength



PDE vs Vex



SPAD integrated into the LF process flow/PDK

- The **collaboration with FBK** was also fruitful **for the integration of SPAD cells into the LFoundry PDK** (on both 110 nm and 150 nm technology nodes).

- **Two flavors of cells have been developed** using MPW (multi project wafers) as vehicles. The **main figures of merit are reported in the next slides**.

- MPW have also been used by **other customers** who **designed their own SPAD cells using the Lfoundry PDK**. An example is shown in the next pages

- **The collaboration with FBK is also reflected on other activities**. Special mention deserves **SUPERTWIN**, funded by the **European Union** for the development of a new generation microscope. The SPAD image sensor was manufactured in Lfoundry using the 110 nm technology.

SPAD integrated into the LF PDK

Main characteristic of the SPAD cells implemented in the 110 nm LFoundry PDK
Characterization data at 20ºC.

	Cell Type1	Cell Type2
size	22.2 µm - 27.2 µm	
BV	18.3 V	20.1 V
Median DCR@ 3V	0.15- 0.19 Hz/µm2	0.15- 0.21 Hz/µm2
PDE peak @3 V	19.8-30.8% 450 nm	16.2%-24.0% 450 nm
PDE#850 nm @3 V	3.2%	3.0%
jitter@831 nm	57.9 - 65 ps	76-80 ps

110 nm technology is optimized for CIS

Main characteristic of the SPAD cells implemented in the 150 nm LFoundry PDK
Characterization data at 20ºC.

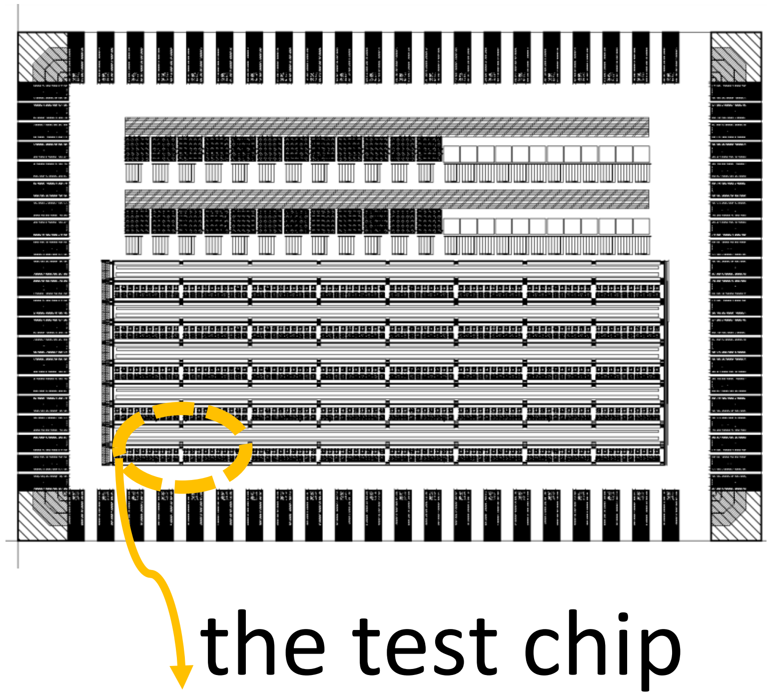
	Cell Type1	Cell Type2
size	15.6 µm2 - 22.5 µm	
BV	18.5 V	23.6 V
Median DCR@ 3V	12.5 Hz/µm2	8 Hz/µm2
PDE peak @3 V	10.8%-15.4% 450 nm	14.9-16.7 % 515 nm
PDE#850 nm @3 V	2.30%	2.30%
jitter@831 nm	42.0 ps	na

SPAD integrated into the LF process flow

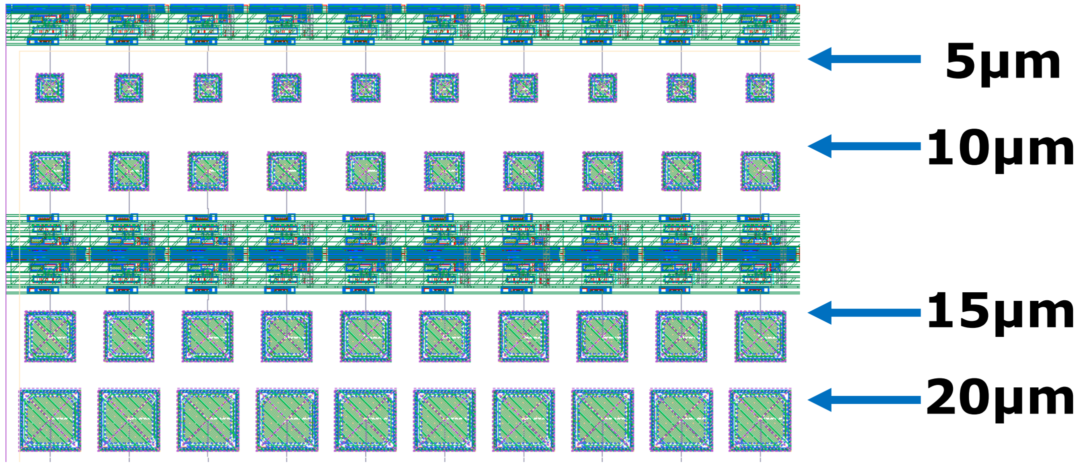
Sensor	**customer1**	**customer2**
Active area (µm2)	78.5	92
DCR (cps/µm2) @ OV	0.76 @ 3 V	0.19 @ 3 V
PDP @wavelenght/OV	52%@460 nm/3 V	22%@455 nm/3 V
PDP @wavelenght/OV	66%@460 nm/6 V	36%@455 nm/6 V
time jitter (ps) @ conditions	87 @846 nm @ 4 V	NA

Main figure of merits **of SPAD cells designed by customers** using LFoundry 110 nm PDK. Few examples to **support the suitability of LF technology for producing SPAD devices**

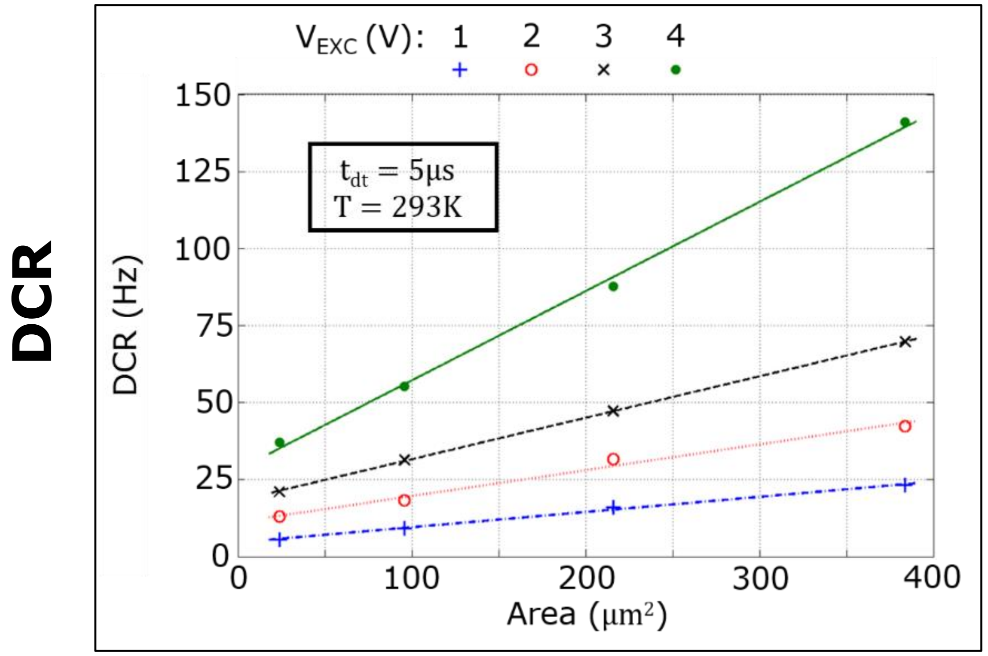
Development of a new generation of optical microscopes to go beyond the Rayleigh limit based on entangled photons



the test chip

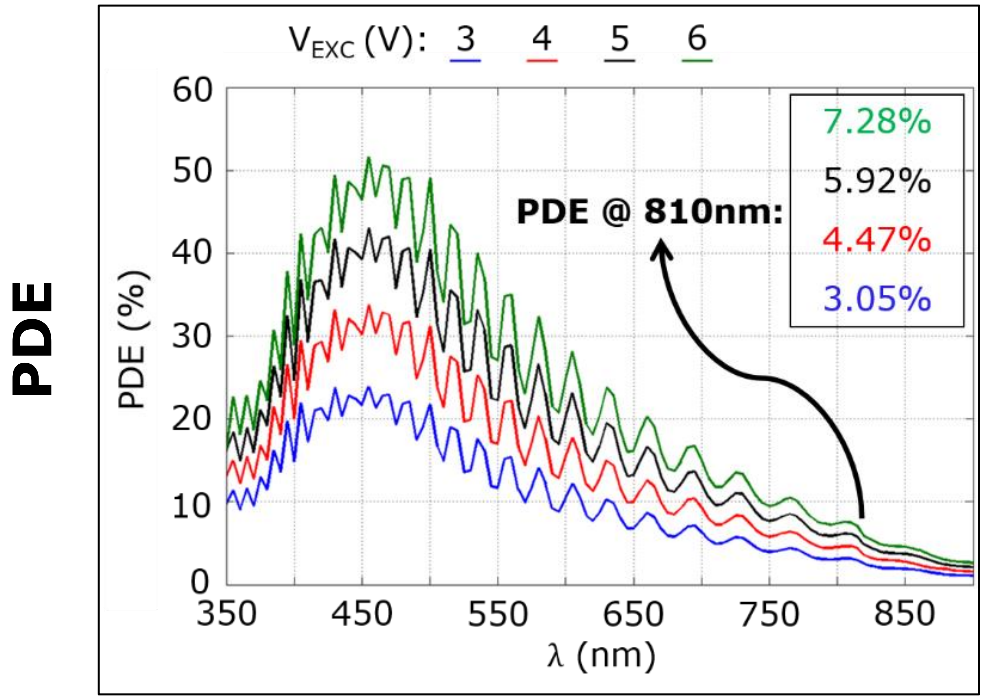


- **Organization of the test chip in 1x20 arrays.**
- **For each flavor, SPADs of 4 different sizes, characterized by their side length, L.**



No big variation with SPAD area.

<u>Low DCR</u> *<u>level</u> even for the smallest cell*



Conclusion

- LFoundry line is **suitable for the production of both SIPMs and SPADs** (line qualified, products running)

- **SPADs are successfully integrated** into the **PDK**, on both **150 nm** and **110 nm** technology nodes, **with good results**;

- **SIPM performances at the status of the art**, equivalent to FBK custom ones, have been achieved and **may be produced in volume** in different flavors.

- **Further development is in place** looking to improve SPAD and SIPM performances exploiting LFoundry process capability

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THANK YOU

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