

CHARACTERISATION OF UFSD4 PRODUCTION BY FBK

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	AS	Compact Muon Solenoid

HISTORY OF UFSD PRODUCTIONS

UFSD4 is the latest UFSD production, featuring **prototypes for the sensor of CMS Endcap Timing Layer** It bears within itself the experience gained with the UFSD R&D productions

- UFSD2: first 50-µm thick batch, focus on gain layer design and radiation hardness • **UFSD3**: studies on carbon doses and gain layer termination structures,
- production of first large multipad structures
- UFSD3.1: exploration of various interpad layouts, optimisation of p-stop doping
- UFSD3.2: optimisation of carbon level, study of different gain layer depths and wafer thicknesses, refinement of interpad design



UFSD1

UFSD2

UFSD3

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UFSD3.1

UFSD3.2

UFSD4









Sensor requirements for the CMS Endcap Timing Layer:

- Timing resolution of $\sigma_{\rm t}=30~{\rm ps}$ up to $\phi\sim 1.5 imes 10^{15}{
 m n_{eq}}/{
 m cm^2}$
- Gain uniformity better than 1% within a sensor
- Low leakage current to limit power consumption and noise lacksquare
- Provide large and uniform signals, >8 fC up to $\phi \sim 1.5 \times 10^{15} n_{eq}/cm^2$
- Minimized "no-gain" area, interpad distance between 50-70 µm
- Pad size $1.3 \times 1.3 \ mm^2$, determined occupancy and read-out electronics

The final sensor will be a 50 μm -thick 16×16 pad array















UFSD4 PRODUCTION

		Gain Layer		
Wafer #	DI	Dose	Carbon	Diffusion
1	Shallow	0.98	0.8	CH-BL
2	Shallow	1.00	1	CH-BL
3	Shallow	0.98	1	CH-BL
4	Shallow	0.98	1	CH-BL
5	Shallow	0.98	0.8	CH-BL
6	Shallow	0.98	0.8	CH-BL
7	Shallow	0.98	0.8	CH-BL
8	Shallow	0.98	0.8	CH-BL
9	Shallow	0.98	0.8	CH-BL
10	Shallow	0.98	0.8 + C0.6	CH-BL
11	Shallow	0.98	0.8 + C0.6	CH-BL
12	Deep	0.75	0.6	CL-BL
13	Deep	0.77	0.6	CL-BL
14	Deep	0.77	0.6	CL-BL
15	Deep	0.77	0.6	CL-BL
16	Deep	0.79	0.6	CL-BL
17	Deep	0.79	0.6	CL-BL
18	Deep	0.79	0.6	CL-BL

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UFSD4 includes 18 wafers with:

- Shallow and deep gain layer
- 6 Boron doses
- 4 different Carbon implants
- 2 diffusion types

Goals of this production:

- design optimisation
- production uniformity
- demonstrate ability of producing large sensors lacksquarewith same characteristics









UFSD4 PRODUCTION

UFSD4 includes single pads, 1x2, 2x2, 5x5 and 16x16 pad arrays with:

- 2 layouts for interpad regions, Type 9 and 10
- 5 different guardring designs: GR3_0, GR3_1, GR3_2, GR5_1, GR5_STD



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CHARACTERISATION OF UFSD4 PRODUCTION

Measurements of all structures performed on wafer by FBK (Trento) A few diced structures have been measured in the Laboratory for **Innovative Silicon Sensors in Torino**

IV studies

- Breakdown voltage maps
- Structures and pads are considered broken if $V_{BD} < 150V$ or $I_{structure, pad} (V < 80 \% V_{BD}) > I_{Thr}$ Production yield evaluation
- Maps and distributions of current @100V for all pads for each wafer Production disuniformity evaluation

CV studies

Depletion voltage maps and distribution for each wafer Gain uniformity evaluation

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PRODUCTION YIELD STUDIES

Maps of **breakdown voltage** for pads used to evaluate **production yield** as ratio between working and total structures and pads

We have a single value for the breakdown voltage of 5-pads lines in 5x5 and 16-pads columns in 16x16 due to measurements setup



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CURRENT UNIFORMITY STUDIES

Maps of leakage current @100V for pads provide indication of production quality and uniformity as ratio between sigma and mean of leakage current distributions



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16x16 are featured with larger values of current as each bin is the sum of leakage current from 16 pads of a column of the device

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FINAL RESULTS ON YIELD AND CURRENT UNIFORMITY

Results for structures yield and for pad current disuniformity in each group of similar wafers

			M			1						
	Wafer group	Sensor Yield [%]	Mean Leakage Current @100 V [A]	Sigma [A]	Disuniformity [%]					Gain Laver		
Small arrays	1	97.22	2.73E-09	4.22E-10	15.5		Wafer Group	Wafer #	DI	Dose	Carbon	Diffusio
	2	97.85	2.42E-08	3.79E-09	15.6		1	1	Shallow	0.98	0.8	CH-BL
	3	99.15	2.20E-08	2.98E-09	13.6		2	2	Shallow	1.00	1	CH-BL
	4	97.08	2.65E-09	4.55E-10	17.2		3	3	Shallow	0.98	1	CH-B
	5	98.51	1.44E-08	1.53E-09	10.7		3	4	Shallow	0.98	1	CH-B
	6	99.15	2.17E-09	1.37E-10	6.33		4	5	Shallow	0.98	0.8	CH-B
	7	98.54	2.51E-09	3.15E-10	12.5		4	6	Shallow	0.98	0.8	CH-B
	8	99.52	2.99E-09	3.16E-10	10.6		4	7	Shallow	0.98	0.8	CH-B
16x16	9	95.97	3.93E-09	3.79E-10	9.64		4	8	Shallow	0.98	0.8	CH-B
	Wafer group	Sensor Vield [%]	Mean Leakage Current @100 V [A]	Sigma [A]	Disupiformity [%]		4	9	Shallow	0.98	0.8	CH-B
	1	83 33	4 92622E-08	3 71298E-09	7 54		5	10	Shallow	0.98	0.8 + C0.6	CH-BL
	2	100.00	4.52762E-07	5 15744E-08	11.39		5	11	Shallow	0.98	0.8 + C0.6	CH-BL
	- 3	91.67	4.04945E-07	3.92497E-08	9.69		6	12	Deep	0.75	0.6	CL-BI
	4	80.00	5.5461E-08	5.95051E-09	10.73		7	13	Deep	0.77	0.6	CL-BI
	5	87.50	2.71854E-07	2.50953E-08	9.23		8	14	Deep	0.77	0.6	CL-BI
	6	66.67	3.73805E-08	7.3242E-10	1.96		8	15	Deep	0.77	0.6	CL-BI
	7	91.67	4.38402E-08	2.58748E-09	5.90		9	16	Deep	0.79	0.6	
	8	100.00	5.16091E-08	1.77389E-09	3.44		9	17	Deep	0.79	0.0	
	9	66.67	6.9986E-08	3.71148E-09	5.30		9	19	Deep	0.77	0.0	
								10	Deep	0.77	0.0	

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GAIN LAYER UNIFORMITY STUDIES

Measurements performed on 16x16 diced structures in the Laboratory for Innovative Silicon Sensors in Torino to extrapolate gain layer uniformity

CV are performed on 25 pads for each of the 6 16x16 structures under test



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GAIN LAYER UNIFORMITY STUDIES

Measurements performed on 16x16 diced structures in the Laboratory for Innovative Silicon Sensors in Torino to extrapolate gain layer uniformity

 V_{foot} is the intersection point of the two lines fitting C(V) curves in the regions corresponding to gain layer and full depletion

 V_{GL} is calculated as:

$$\mathbf{V_{GL}} = \frac{\mathbf{V_{foot}}}{1 + 2\frac{\mathbf{d}}{\mathbf{w}}}$$

d: gap between n+ and gain layer w: gain layer width



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GAIN LAYER UNIFORMITY STUDIES

Gain layer disuniformity measured on 3 sensors for each group Obtained as ratio between sigma and mean values of $V_{depletion}$ distributionsWafer group visot [V]UDoseCarbonWafer group visot [V]Visot [V]V											Gain Layer		
group 1 1 Shallow 0.98 0.8 0.8 Obtained as ratio between sigma and mean values of 2 2 Shallow 1.00 1 0 Vapletion distributions 3 3 Shallow 0.98 1 0 Wafer group V_foot [V] Sigma V_foot [V] V_foot [V] Sigma V_GL [V] V_GL 4 5 Shallow 0.98 1 0 4 22.53 0.20 V_foot [V] V_foot [V] Sigma V_GL [V] V_GL 4 4 5 Shallow 0.98 0.8 CC 4 22.53 0.20 0.89 3.76 0.03 0.89 5 10 Shallow 0.98 0.8 CC 4 22.53 0.20 0.89 3.76 0.03 0.89 5 10 Shallow 0.98 0.8 CC 5 11 Shallow 0.98 0.8+C0.6 CC 7 13 Deep 0.77 0.6 CC 8 15 Deep 0.77 0.6	Gain layer disuniformity measured on 3 sensors for each							Wafer Group	Wafer #	DI	Dose	Carbon	Dif
2 2 Shallow 1.00 1 0 Obtained as ratio between sigma and mean values of $V_{depletion}$ istributions 3 3 Shallow 0.98 1 C Wafer group V_foot [V] Sigma V_foot [V] V_GL [V] Sigma V_GL [V]	aroun								1	Shallow	0.98	0.8	C
Obtained as ratio between sigma and mean values of $V_{depletion}$ distributions 3 3 Shallow 0.98 1 CC V_depletion distributions Water group V_foot [V] V_foot [V] V_GL [V] V_GL [V] V_GL 4 6 Shallow 0.98 0.8 CC 4 Shallow 0.98 0.8 CC 4 Shallow 0.98 0.8 CC 4 Shallow 0.98 0.8 CC 6 12 </th <th>Obtelier</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th>2</th> <th>2</th> <th>Shallow</th> <th>1.00</th> <th>1</th> <th>C</th>	Obtelier							2	2	Shallow	1.00	1	C
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Obtaine	ed as r	atio betwe	en sigma a	ana me	ean values	5 OT	3	3	Shallow	0.98	1	С
4 5 Shallow 0.98 0.8 C Wafer group V_foot [V] V_foot [V] V_foot [V] V_GL [V] Sigma V_GL [V] V_GL 4 22.53 0.20 0.89 3.76 0.03 0.89 8 47.66 0.10 0.22 4.77 0.01 0.22 Shallow 0.98 0.8 C 4 22.53 0.20 0.89 3.76 0.03 0.89 8 47.66 0.10 0.22 4.77 0.01 0.22 5 10 Shallow 0.98 0.8 + C0.6 C 6 12 Deep 0.75 0.6 C 8 14 Deep 0.77 0.6 C 8 14 Deep 0.77 0.6 C 9 18 Deep 0.77 0.6 C 9 18 Deep 0.79 0.6 C	V_{I} .	dist	ributions					3	4	Shallow	0.98	1	С
Mafer group V_foot V_foot V_GL (M) Sigma V_GL (M) V_GL (M) Sigma V_GL (M) V_GL (M) V_GL (M) Sigma V_GL (M) V_GL (M) Main	' depleti	on didt						4	5	Shallow	0.98	0.8	С
Wafer group V_foot V_foot V_GL [V] Sigma V_GL [V] V_GL Mainformity [%] Mainformity [%] <th></th> <td></td> <td></td> <td></td> <td></td> <td></td> <th></th> <td>4</td> <td>6</td> <td>Shallow</td> <td>0.98</td> <td>0.8</td> <td>С</td>								4	6	Shallow	0.98	0.8	С
Image: state stat	Wafer group	V_foot [V]	Sigma V_foot [V]	V_foot	V_GL [V]	Sigma V_GL [V]	V_GL	4	7	Shallow	0.98	0.8	С
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4 22.53 0.20 0.89 3.76 0.03 0.89 0.98 0.84 c 0.6 0.00	-							4	9	Shallow	0.98	0.8	С
8 47.66 0.01 0.22 4.77 0.01 0.22 5 11 Shallow 0.98 0.8 + C0.6 0 Same results for V_{foot} and V_{GL} disuriformities 5 11 Shallow 0.98 0.8 + C0.6 0 8 14 Deep 0.77 0.6 0 9 16 Deep 0.79 0.6 0 9 17 Deep 0.79 0.6 0 9 18 Deep 0.79 0.6 0	4	22.53	0.20	0.89	3.76	0.03	0.89	5	10	Shallow	0.98	0.8 + C0.6	C
Same results for V_{foot} and V_{GL} disuniformities $\begin{pmatrix} 6 \\ 7 \\ 7 \\ 8 \\ 8 \\ 14 \\ Deep \\ 0.77 \\ 0.6 \\ 0 \\ 9 \\ 16 \\ Deep \\ 0.77 \\ 0.6 \\ 0 \\ 9 \\ 16 \\ Deep \\ 0.77 \\ 0.6 \\ 0 \\ 9 \\ 18 \\ Deep \\ 0.79 \\ 0.6 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ $	8	47.66	0.10	0.22	4.77	0.01	0.22	5	11	Shallow	0.98	0.8 + C0.6	C
Same results for V_{foot} and V_{GL} disuniformities $\begin{pmatrix} 7 & 13 & Deep & 0.77 & 0.6 & 0.6 \\ 8 & 14 & Deep & 0.77 & 0.6 & 0.6 \\ 9 & 16 & Deep & 0.79 & 0.6 & 0.6 \\ 9 & 17 & Deep & 0.79 & 0.6 & 0.6 \\ 9 & 18 & Deep & 0.79 & 0.6 & 0.6 \\ 9 & 18 & Deep & 0.79 & 0.6 & 0.6 \\ 9 & 18 & Deep & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.79 & 0.79 & 0.6 & 0.79 \\ 0 & 0 & 0 & 0 & 0.79 & 0.$								6	12	Deep	0.75	0.6	C
Same results for V_{foot} and V_{GL} disuniformities $\begin{vmatrix} 8 & 14 & Deep & 0.77 & 0.6 & C \\ 8 & 15 & Deep & 0.77 & 0.6 & C \\ 9 & 16 & Deep & 0.79 & 0.6 & C \\ 9 & 17 & Deep & 0.79 & 0.6 & C \\ 9 & 18 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 &$								7	13	Deep	0.77	0.6	C
8 15 Deep 0.77 0.6 C 9 16 Deep 0.79 0.6 C 9 17 Deep 0.79 0.6 C 9 17 Deep 0.79 0.6 C 9 18 Deep 0.79 0.6 C	Same results for $V_{\rm e}$ and $V_{\rm e}$ disuniformities						8	14	Deep	0.77	0.6	C	
9 16 Deep 0.79 0.6 C 9 17 Deep 0.79 0.6 C 9 18 Deep 0.79 0.6 C	Game results for <i>foot</i> and <i>GL</i> disumbrinities							8	15	Deep	0.77	0.6	C
9 17 Deep 0.79 0.6 C 9 18 Deep 0.79 0.6 C								9	16	Deep	0.79	0.6	C
9 18 Deep 0.79 0.6 C									17	Deep	0.79	0.6	C
								9	18	Deep	0.79	0.6	C

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UFSD4 is the latest UFSD production by FBK including prototypes of the CMS ETL sensor The aim is to demonstrate the capability of producing the large sensors with similar characteristics and good yield

The whole production has been characterised with **measurements** performed both **on wafer by FBK** A few diced structures have been tested at the Laboratory for Innovative Silicon Sensors in Torino More measurements will come in the next months

Results on yield and current uniformity:

- Percentage of working devices >96% in small arrays and >67% in 16x16 matrices
- Low mean values for leakage current @100 V
- Maximum current disuniformity is 17% in small devices and 11% in 16x16 arrays

Results on gain layer uniformity:



• Spread of gain layer depletion voltage lower than 1% for both wafers with shallow and deep gain implants





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MEASUREMENT REPRODUCIBILITY

Wafer	Good columns ratio A [%]	Good columns ratio B [%]	Good columns ratio
Ę	84.375	84.375	
e	100	100	

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