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Development of Novel On-Chip, Customer-Design Spiral Biasing Adaptor for Si Drift Detectors and Detector Arrays for X-ray and Nuclear Physics Experiments

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3. Design of SBA
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1 Introduction

1. **The current Spiral SDD was designed such that each SDD single cell has its own biasing spiral, which is also used as the definition of the p-n junction on the surface [1-3];**

2. **The power is therefore $P_s=V_{out}^2/R_{spiral}$ (~100^2/10MΩ=1 mW/cell) for a single cell and $P=N^2 \text{x} P_s$ for a SDD array of $N\text{x}N$, which can be large (e.g. for N=100, P=10 W) ;**

3. **The heat generated by this power stays with the SDD, making it hard to cool down necessary for low leakage current;**

Introduction (continue)

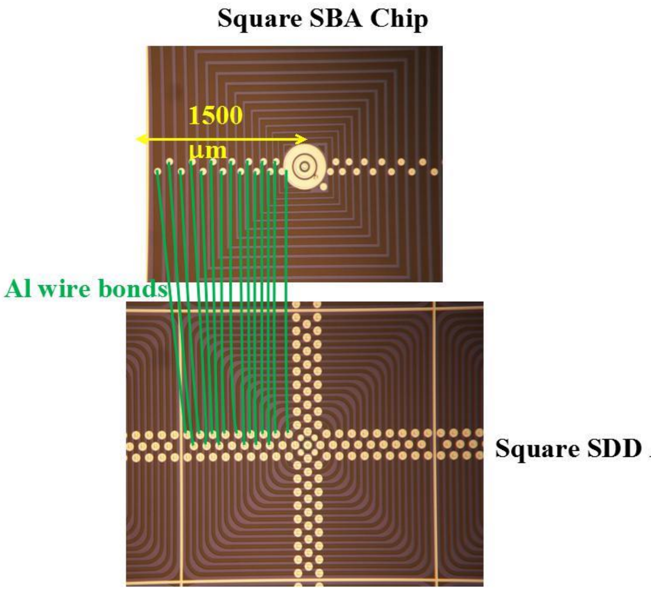
4. The new SBA

   a) will separate the biasing and p-n junction definition
   b) is designed and processed the same as SDD in geometry and in wafer;
   c) less powers consumption (one SBA per SDD array);
   d) SDD has the same geometry as SBC (i.e. pitch $p=p(r)$); implant width $W=W(r)$ can be 80 to 90% of $p(r)$ --- minimum surface area;

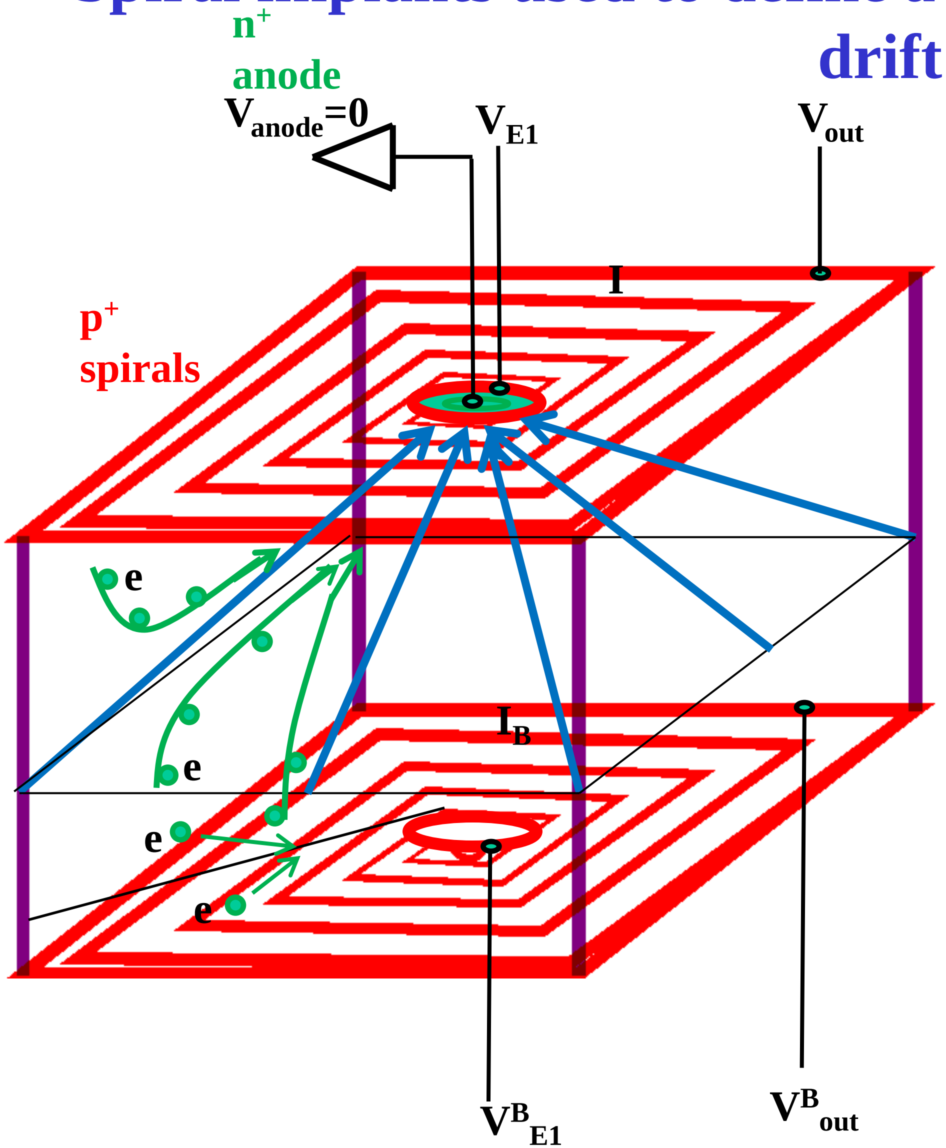
5. Only a few bonds are needed to connect SBA and SDD;

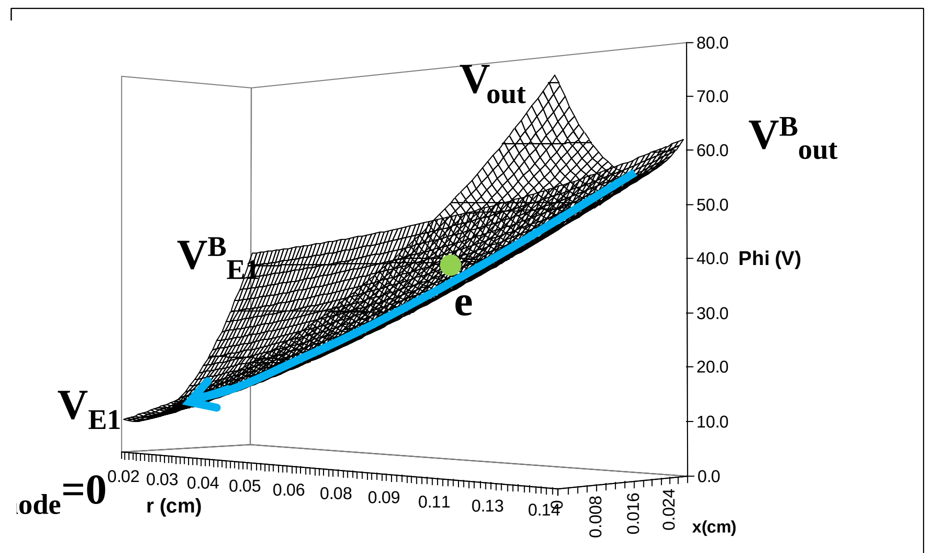
6. It may stay on the same SDD chip (not severed off) for easy one metal/two metal connections to the SDD

5. The biasing on the SDD array can be interconnected by one or two metal process depending on the value of V_{out};



Spiral square SDD single Cell ---- Good for packing in space
Spiral implants used to define a constant drift field --- minimum drift time





$$V^B_{E1} = 0.9V_{fd} + \gamma V_{E1}$$

$$V_{out} = 2V_{fd}$$

$$V^B_{out} = V^B_{E1} + \gamma V_{out}$$

$(\gamma = 0.3$ here)

If we only bias V^B_{E1} (or bias $V^B_{E1} = V^B_{out}$, $\gamma=0$), it will be the same as biasing the backside uniformly

2

Concept of Spiral Biasing Adapter (SBA) ---
Separation of biasing and SDD field-define-rings

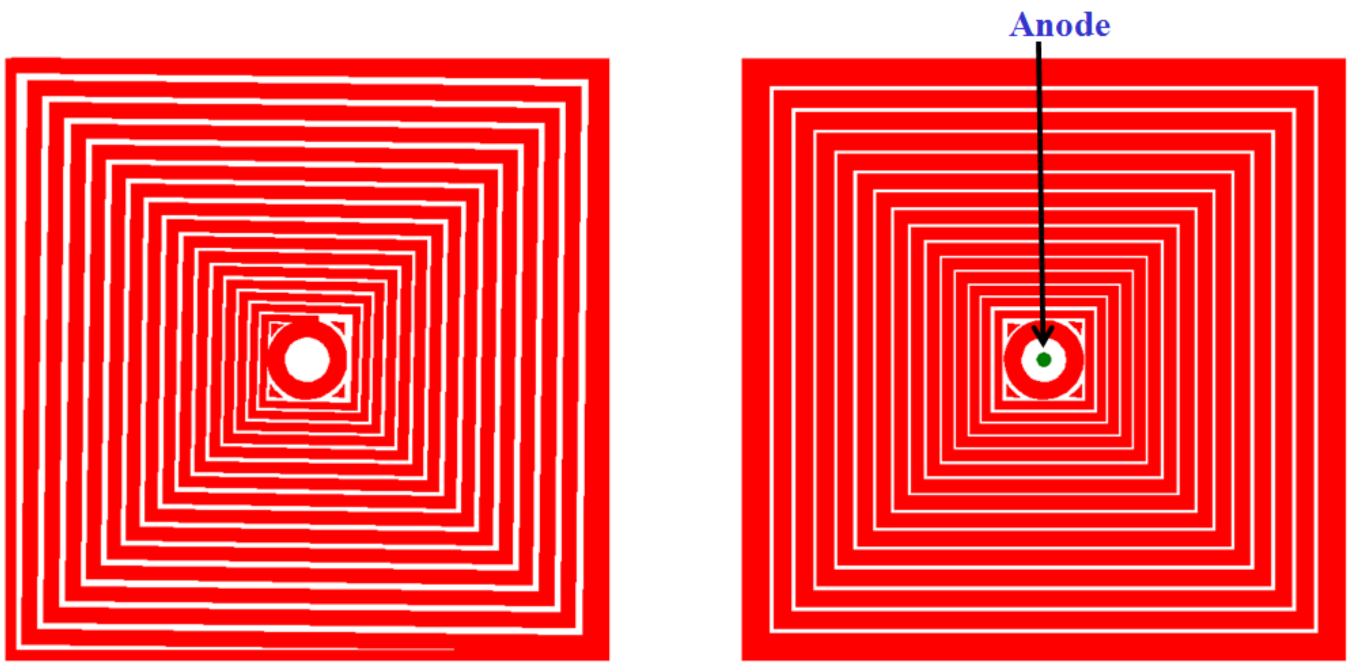
The SBA is designed to give optimum drift field in the SDD drift channel (See 3), with a given pitch (p) and width (W) to radius (r) relations: $p_{SBA}(r)$ And $W_{SBA}(r)$.

The actual SDD ring would Would be designed with the Same $p_{SBA}(r)$: i.e.

$p_{SDD}(r) = p_{SBA}(r)$

But relaxed $W_{SDD}(r)$, e.g.

$W_{SDD}(r) = 0.8\, W_{SDD}(r)$



SBA(I_S) Single SDD Cell

Fig. 2 a) the SBA chip, and b) the matching single SDD cell.
Here $p_{SDD}(r))=p_{BSA}(r))$, and $W_{SDD}(r))= 0.8 \cdot p_{SDD}(r)$.

3 Design of SBA

For the backside potential proportional to the front side one (symmetrical SDD):

$$\Psi(r) = |V_B| + \gamma\,\Phi(r) \qquad (0 \le \gamma \le 1) \qquad \textbf{(1)}$$

If $\gamma = 0$, it is the usual uniform backside biasing.

In the drift channel, the optimum E-field is a constant drift field $E_{dr,r}(r) = E_{dr,r}$

It can be shown [4] that the potential and field on the front surface (the side with biasing spirals):

$$\Phi(r) = \frac{(1-\gamma)|V_B| + (1+\gamma)V_{fd}}{(1-\gamma)^2} - \sqrt{[\frac{(1-\gamma)|V_B| + (1+\gamma)V_{fd}}{(1-\gamma)^2} - |V_{E1}|]^2 - \frac{4V_{fd}E_{dr,r}\,(r-r_1)}{(1-\gamma)^2}} \qquad \textbf{(2)}$$

$$E(r) = \frac{2V_{fd}E_{dr,r}}{(1-\gamma)^2}\,\frac{1}{\sqrt{[\frac{(1-\gamma)|V_B| + (1+\gamma)V_{fd}}{(1-\gamma)^2} - |V_{E1}|]^2 - \frac{4V_{fd}E_{dr,r}\,(r-r_1)}{(1-\gamma)^2}}} \qquad \textbf{(3)}$$

The spiral pitch *p(r)*, width *W(r)*, front surface field *E(r)*, implant sheet resistance ρ_s, current *I*, and length of each turn *α* are related as the following [2,4]:

$$\rho_s I \alpha r = E(r) W(r) p(r) \quad \textbf{(4)}$$

For given E(r) (Eq. (3)), and a square root pitch dependence:

$$p(r) = p_1 \sqrt{\frac{r}{r_1}}$$

We have the spiral :

$$r = \left[\sqrt{r_1} + \frac{p_1 \varphi}{4\pi \sqrt{r_1}} \right]^2 \quad \textbf{(5)}$$

and the width *W(r) of the SBA* can be determined as:

$$W(r) = \frac{\rho_s I \alpha \sqrt{r r_1}}{E(r) p_1} \quad \textbf{(6)}$$

4 Design of SDD cell

For a SDD cell with designed optimum drift electric field as defined by SBA, we only need:

$$p_{SDD}(r) = p_{SBA}(r) \qquad \textbf{(7)}$$

for the SDD ring (closed) pitch

The restriction of the ring width no longer exist. In fact, to minimize the un-implanted area in the front side, and thus get more uniform field near the surface, we can make the ring width much larger, e.g. we can choose:

$$W_{SDD}(r) = 0.8 \cdot p_{SDD}(r) \qquad \textbf{(8)}$$

To avoid singularity in *E(r)* at *r = R* (reach-through) we should keep in mind the following conditions satisfied in design and operation:

$$\begin{cases} |V_B| \le V_{fd} \\ |V_{out}| < \dfrac{(1-\gamma)|V_B| + (1+\gamma)V_{fd}}{(1-\gamma)^2} \le \dfrac{2V_{fd}}{(1-\gamma)^2} \end{cases} \qquad (9)$$

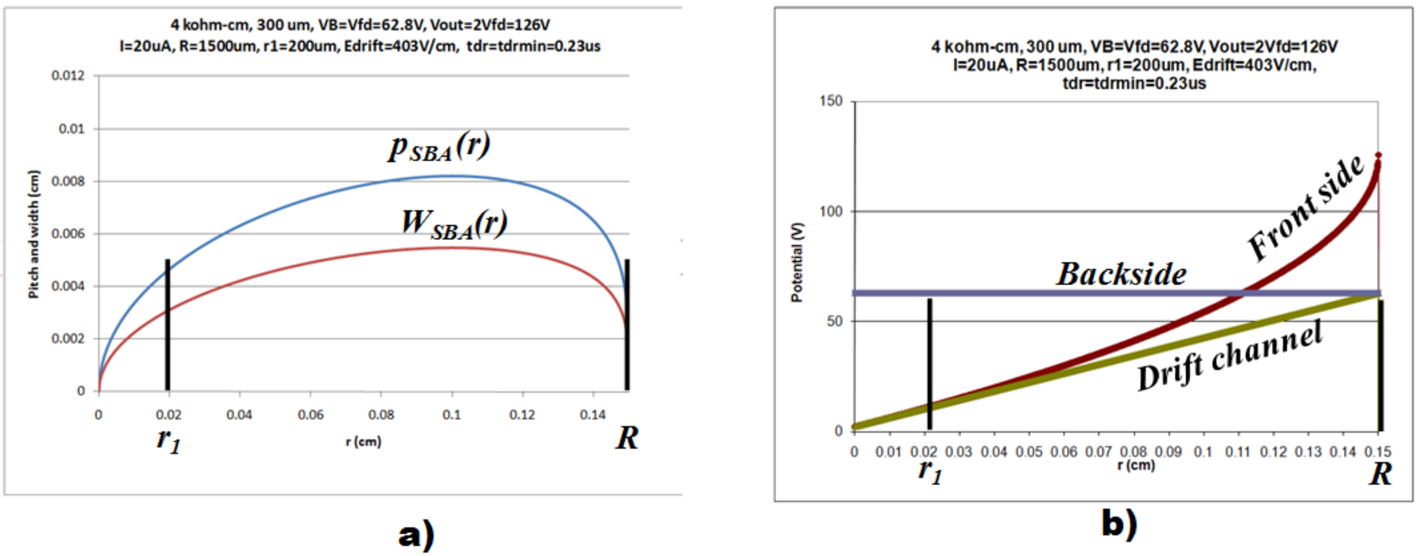


Fig. 3 An example of the calculation results for a SBA and marching single SDD cell (γ=0):

a) pitch ($p_{SBA}(r)$) and width ($W_{SBA}(r)$) profiles of the SBA;

b) and b) the resulting negative potential profiles in the SDD cell for the given set of conditions.

Some design options of SBA and SDD

i) Low current option

Since narrow width of SBA gives low biasing current in SBA, we can Use it to get much reduced biasing current and therefore reduced heat:

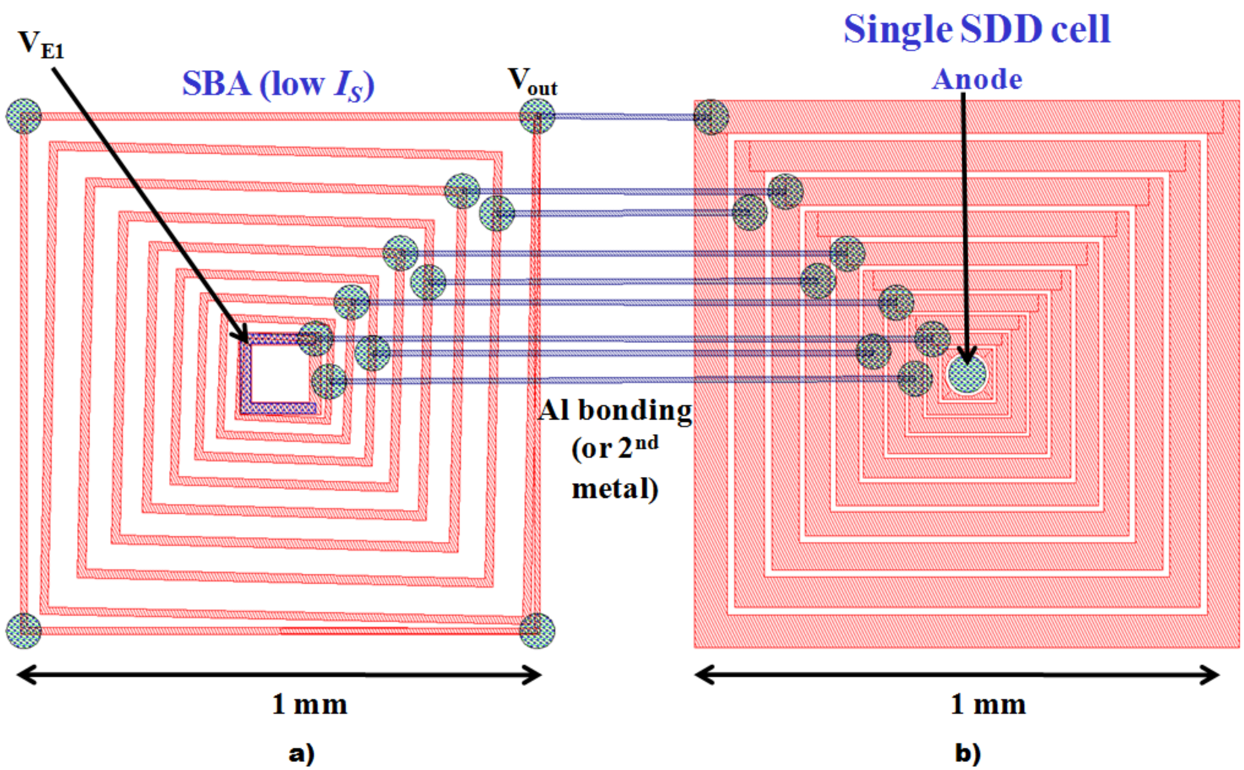
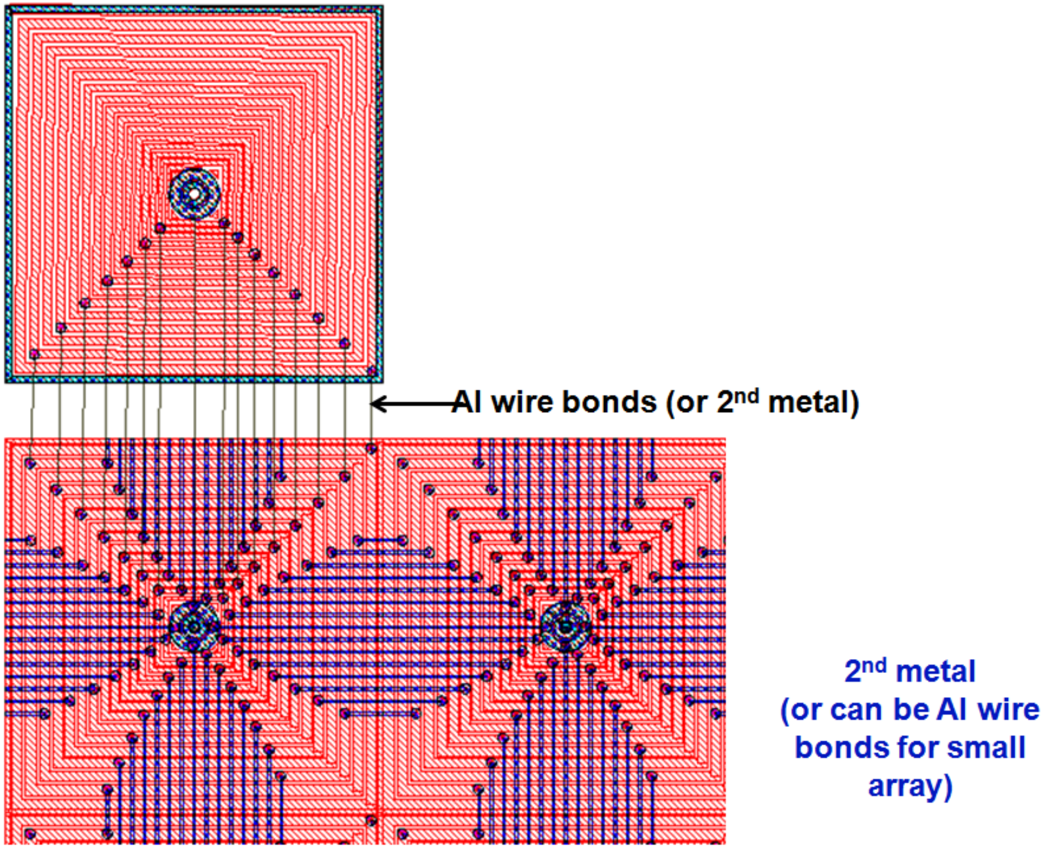


Fig. 4 An example of SBA chip with narrow spiral implants for reduce current (5 μA here) and the matching single SDD cell with much wider implant rings.
Here $p_{SDD}(r)) = p_{BSA}(r))$, and $W_{SDD}(r)) = 0.8 \cdot p_{SDD}(r)$.

ii) Interconnection options

Al wire bonds between SBA and SDD: the SBA chip can be physically severed from the SDD chip: no heat transfer from SBA and SDD ----- good for high biasing current

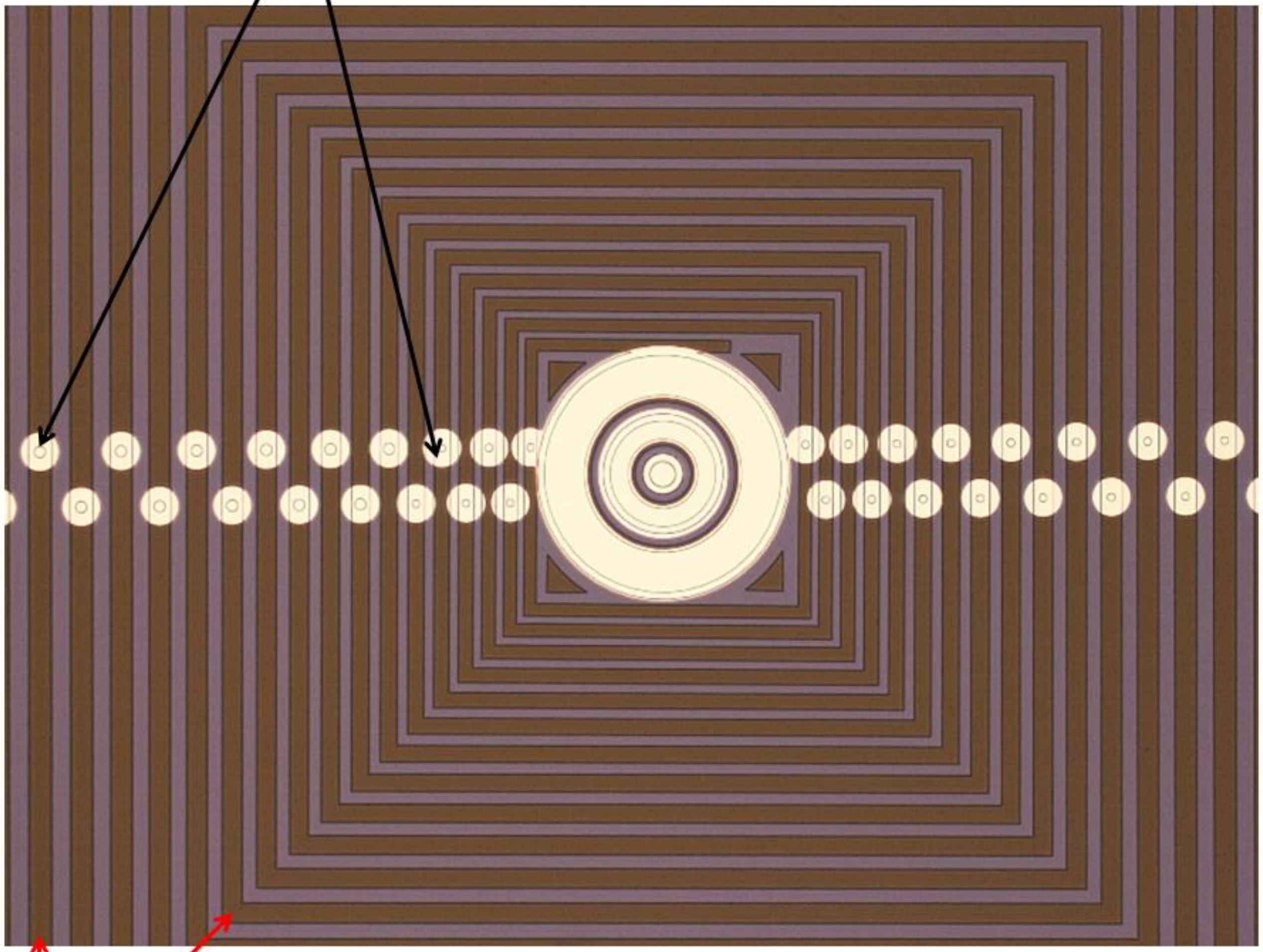


2nd metal between SBA and SDD: ----- good for low biasing current

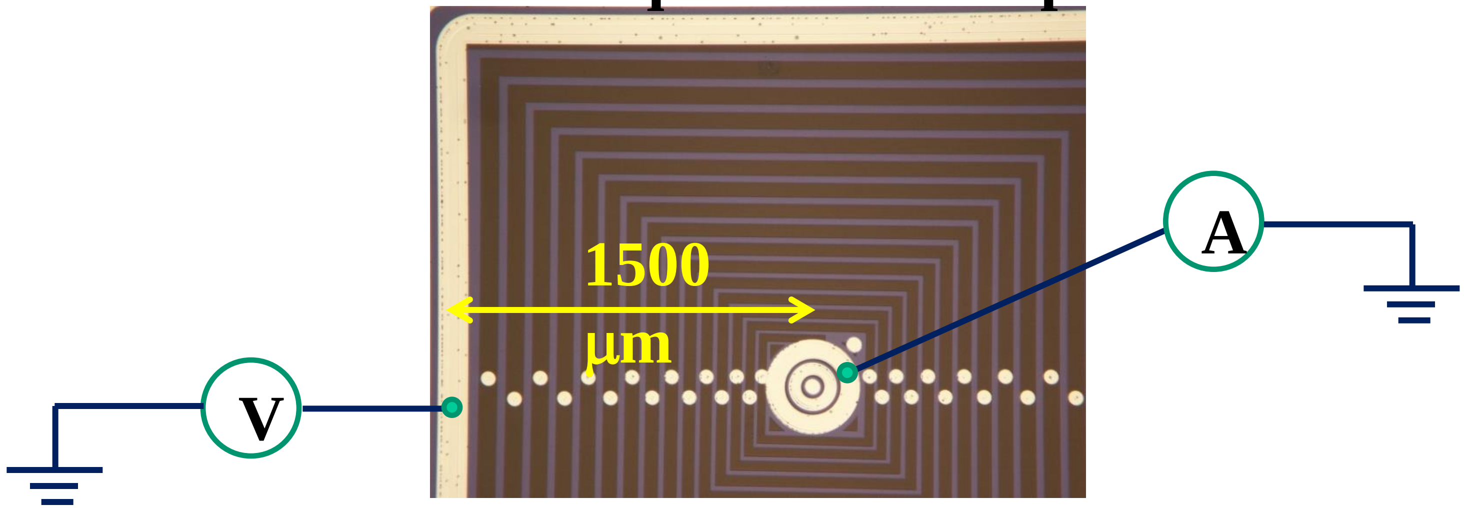
The interconnection between SDD cells should be 2nd metal. But Al wire bonds can also be used for small array

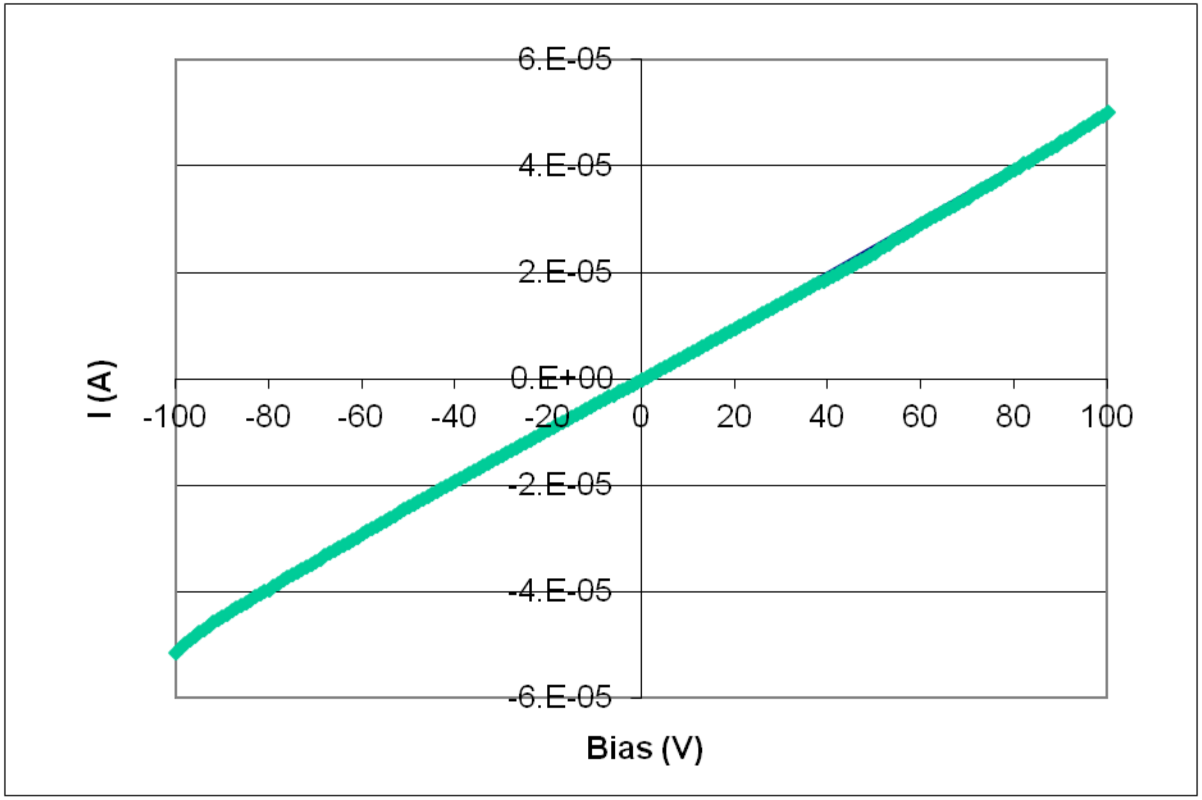
First prototype processing

The first prototype of SBA has been mad at BNL

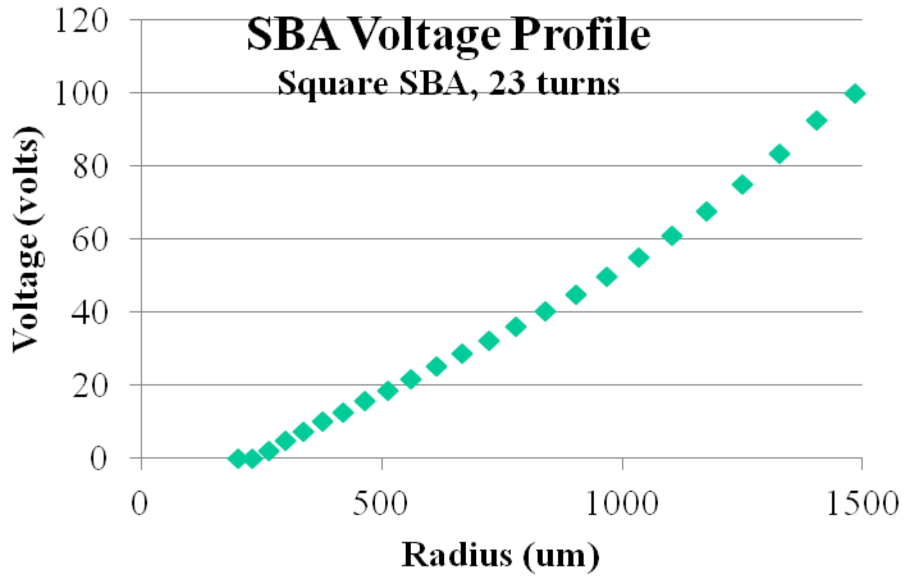


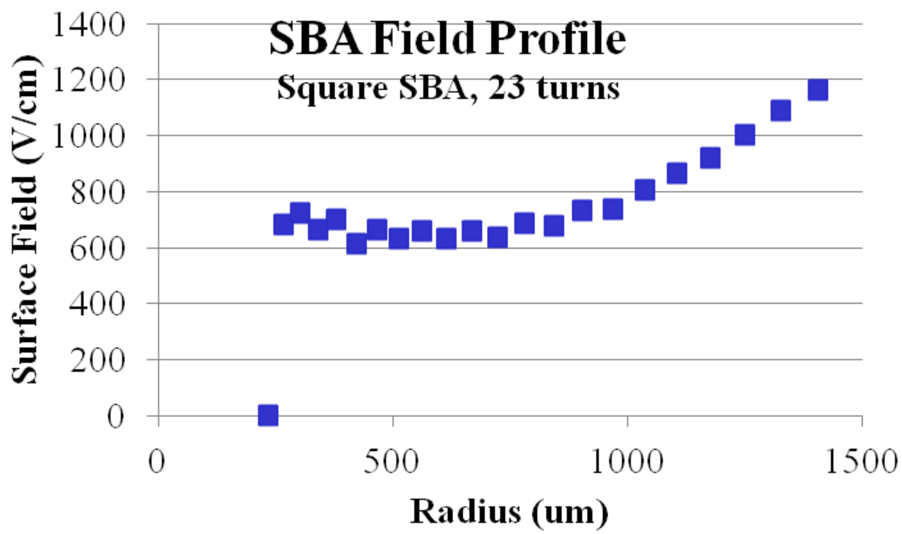
Square SBA Chip



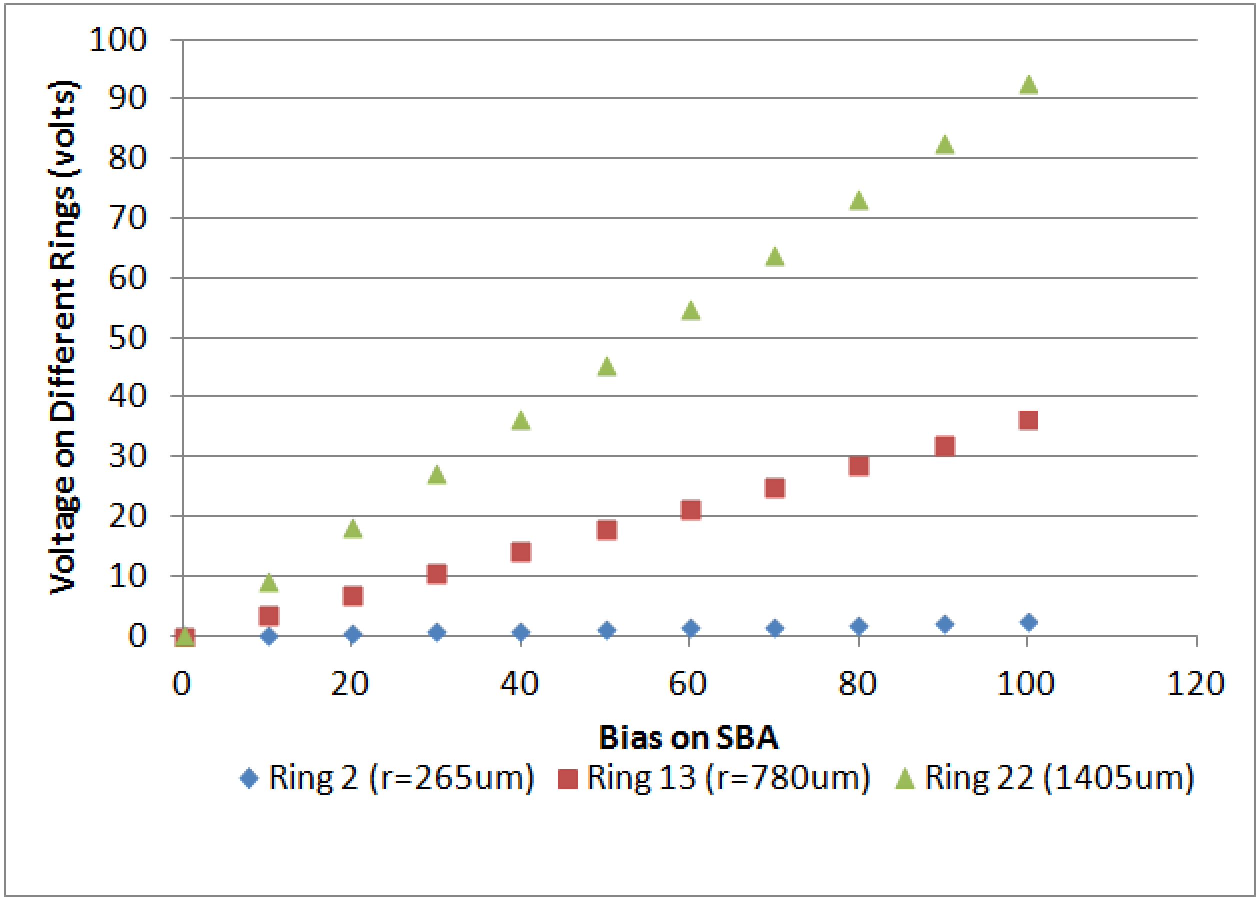


Square SBA Voltage distribution



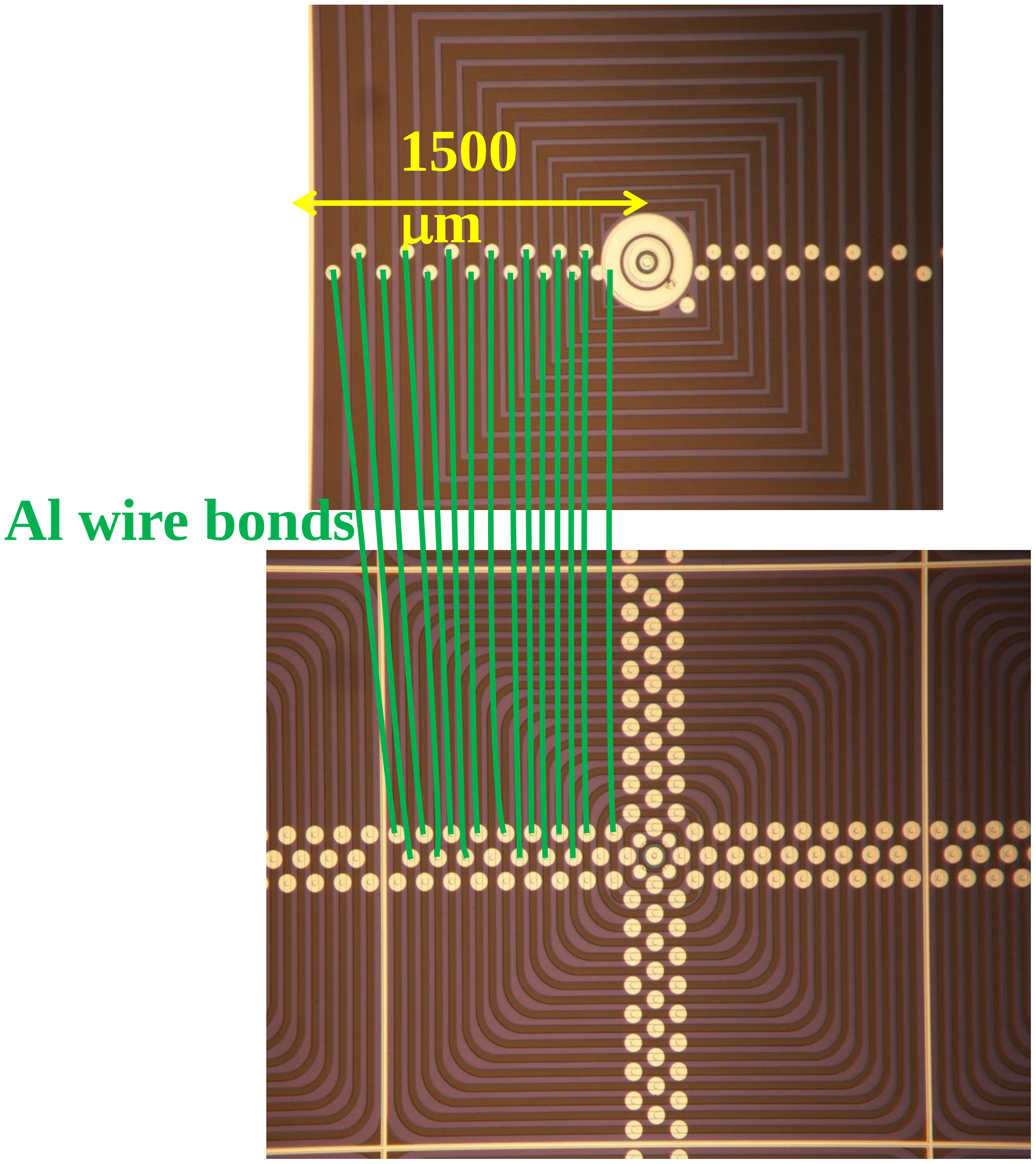


Square SBA Voltage distribution on SBA bias voltage



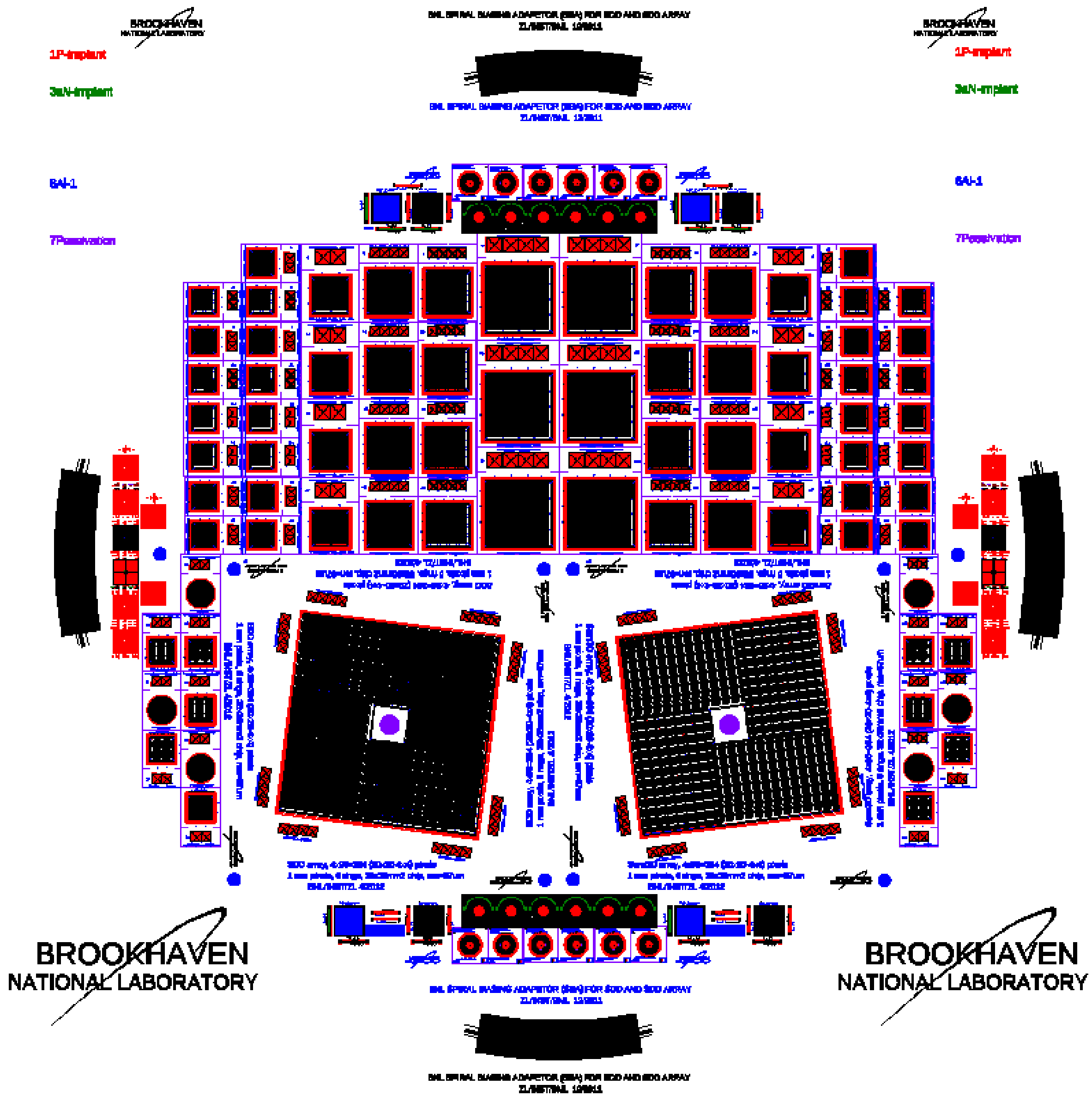
Linear dependences

Square SBA Chip

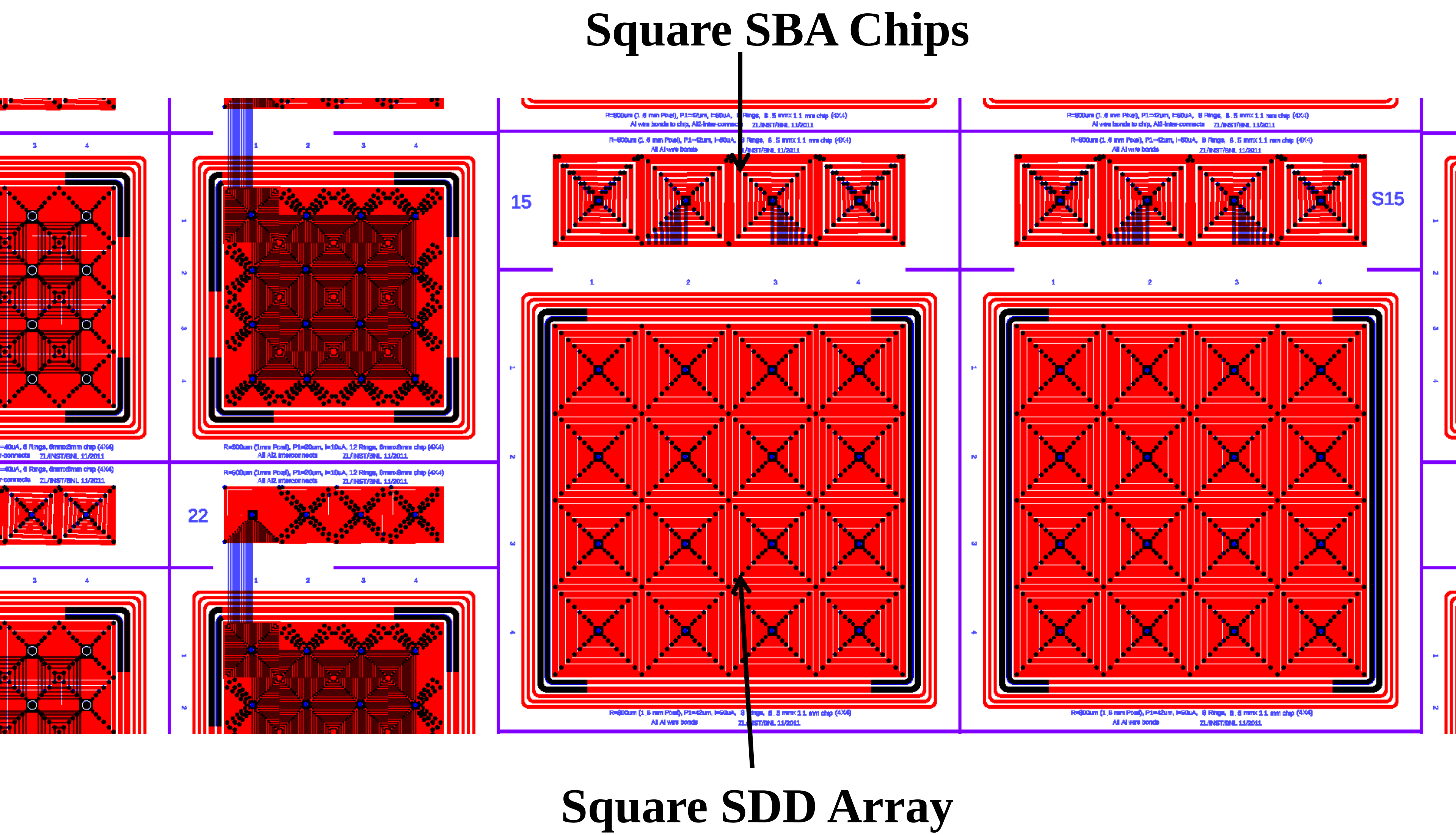


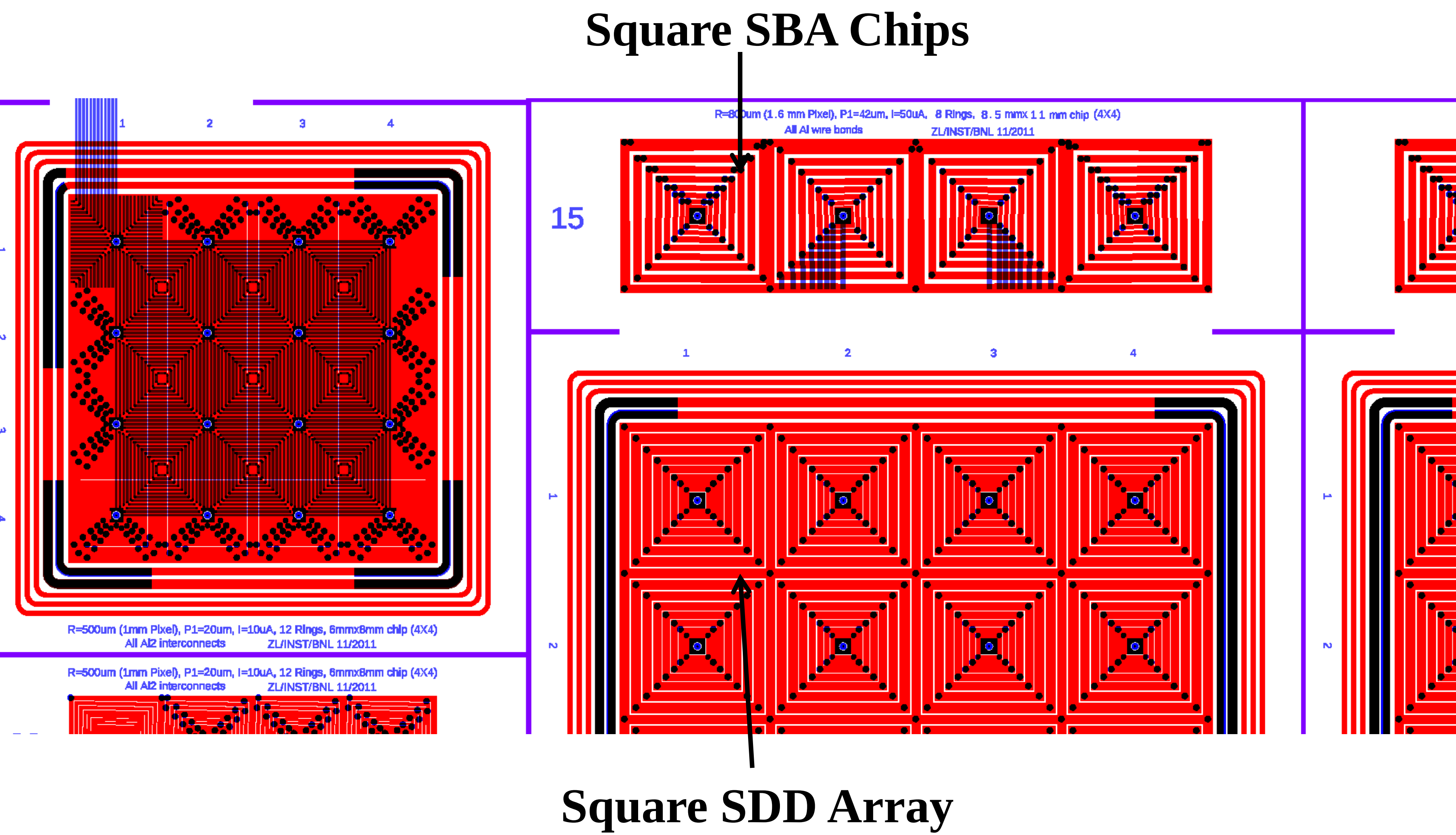
Square SDD Array

Design of SBA Chip integrated with SDD and SDD arrays



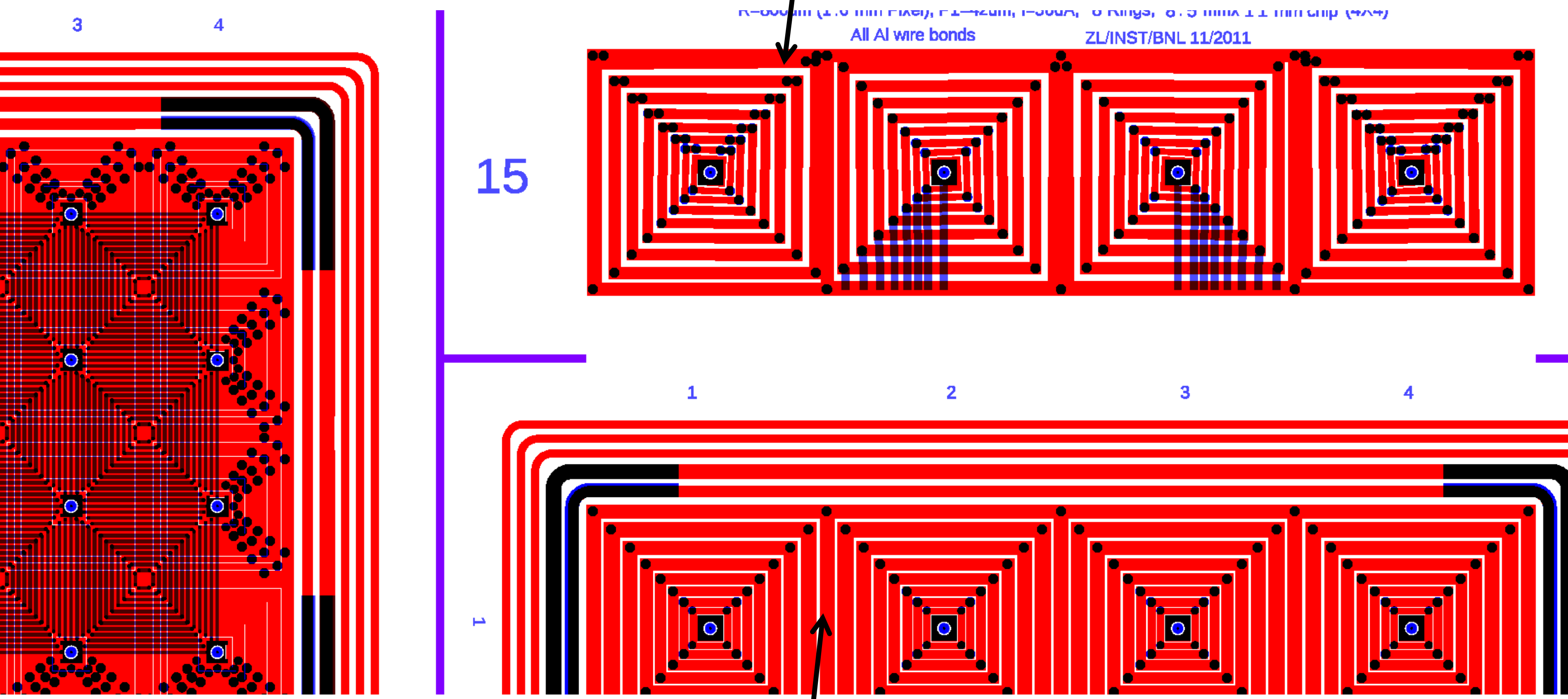
Detector processing will soon begin


Square SBA Chips
15
S15
22
Square SDD Array

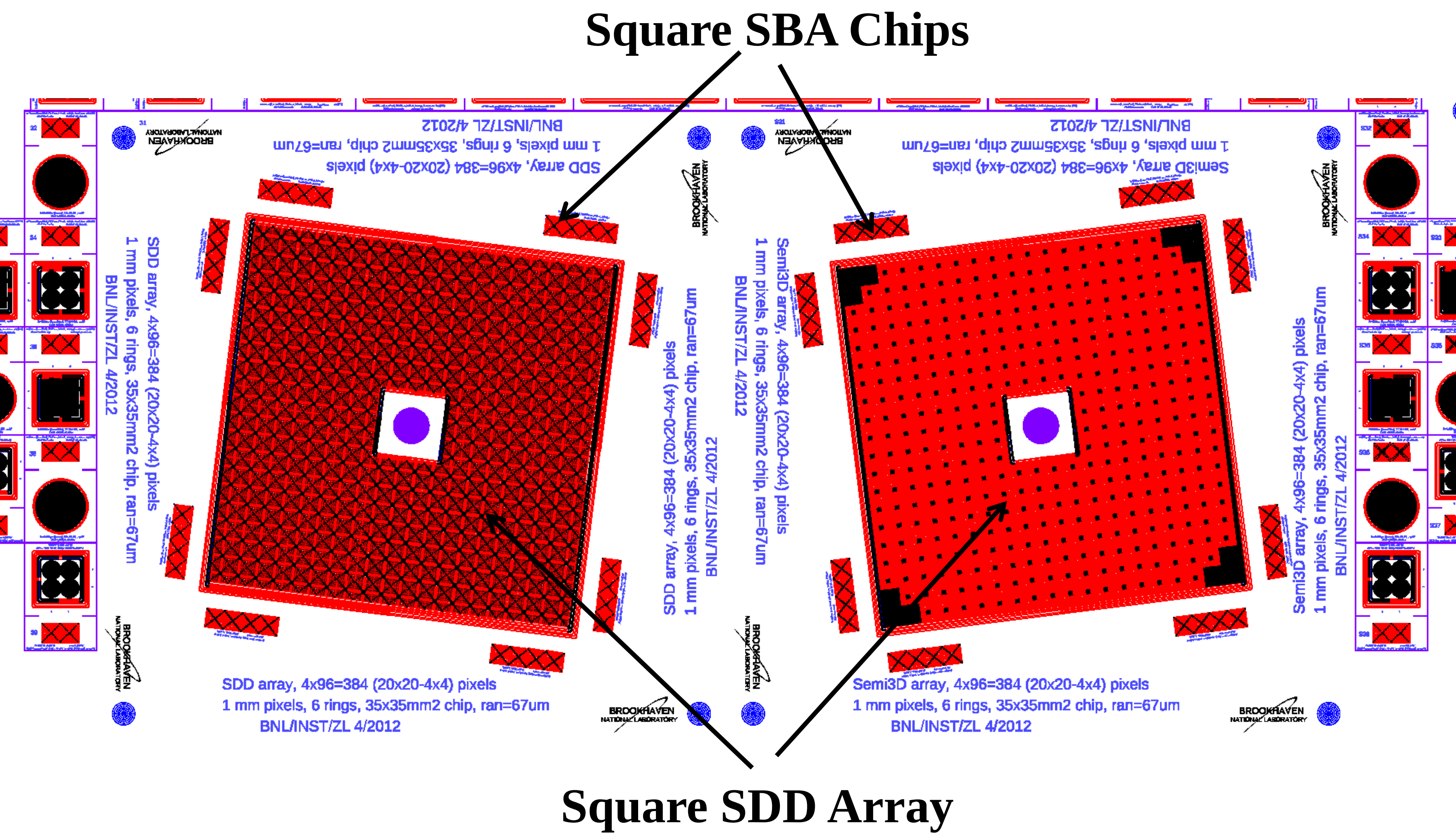


Square SBA Chips
R=800um (1.6 mm Pixel), P1=42um, I=50uA, 8 Rings, 8.5 mmx 11 mm chip (4X4)
All Al wire bonds
ZL/INST/BNL 11/2011
15
R=500um (1mm Pixel), P1=20um, I=10uA, 12 Rings, 6mmx8mm chip (4X4)
All Al2 interconnects
ZL/INST/BNL 11/2011
Square SDD Array

Square SBA Chips



Square SDD Array


Square SBA Chips
SDD array, 4x96=384 (20x20-4x4) pixels
1 mm pixels, 6 rings, 35x35mm2 chip, ran=67um
BNL/INST/ZL 4/2012
Semi3D array, 4x96=384 (20x20-4x4) pixels
1 mm pixels, 6 rings, 35x35mm2 chip, ran=67um
BNL/INST/ZL 4/2012
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NATIONAL LABORATORY
Square SDD Array

7 Summary

1. Novel On-Chip Spiral Biasing Adapter (SBA) has been proposed
2. SBA has achieved the separation of biasing and SDD field-define-rings
3. Design of SBA and SDD rings are competiple
4. First prototype of SBA has been made
5. First protype of SBA with SDD is on the way

References

[1] P. Rehak et al., "Spiral Si Drift Detectors", IEEE Trans. Nucl. Sci., Vol. 36, No. 1, 203-209 (1989)

[2] P. Rehak et al.,"Array of Silicon Drift Detectors for an Extraterrestrial X-ray Spectrometer", Nucl. Instr. and Meth. A, 624, 260-264 (2010)

[3] W. Zhang et al., IEEE Trans. Nucl. Sci., Vol. 47, No. 4, 1381-1385 (2000)

[4] Z. Li, , Nuclear Instruments & Methods in Physics Research A (2013), http://dx.doi.org/10.1016/j.nima.2013.06.066i