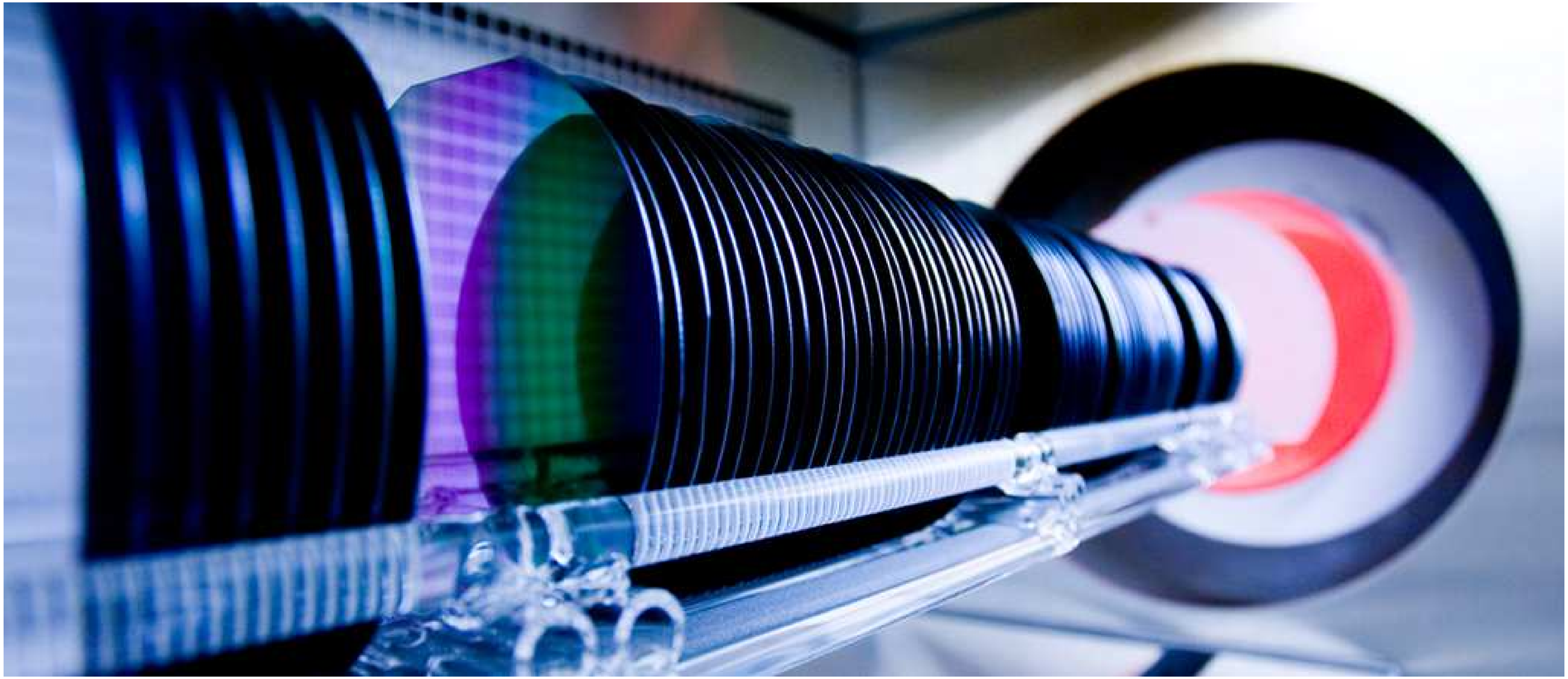


First concepts for 3D radiation detector manufacturing at CiS

K. Lauer, R. Täschner, S. Völlmeke, L. Long, T. Wittig, A. Lawerenz, R. Röder

10th Anniversary "Trento"
Workshop on Advanced Silicon Radiation Detectors
19.02.15, Trento

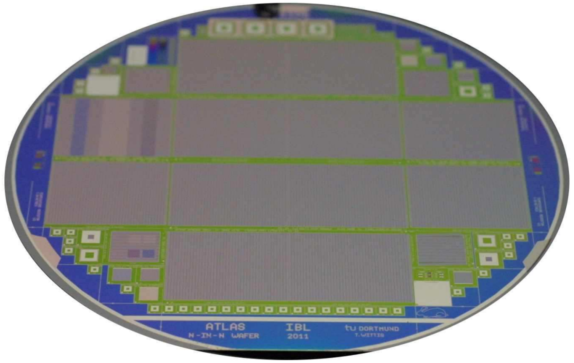
Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH

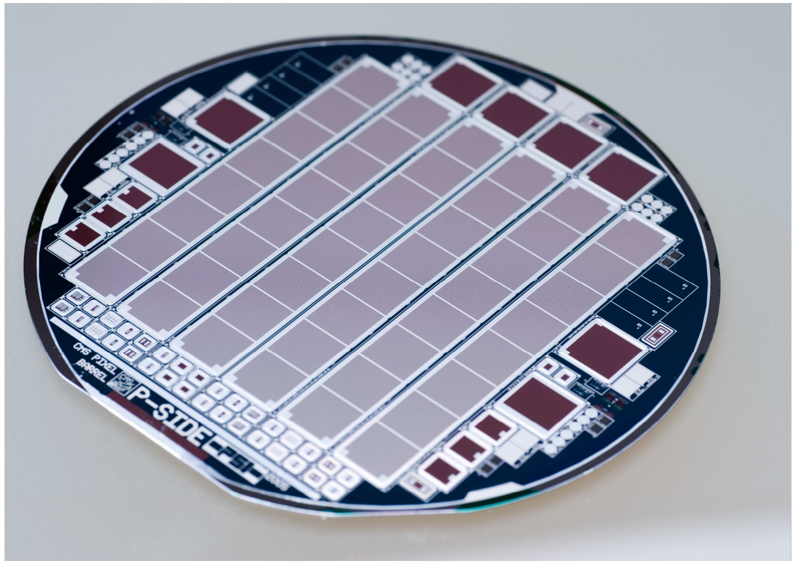
Overview

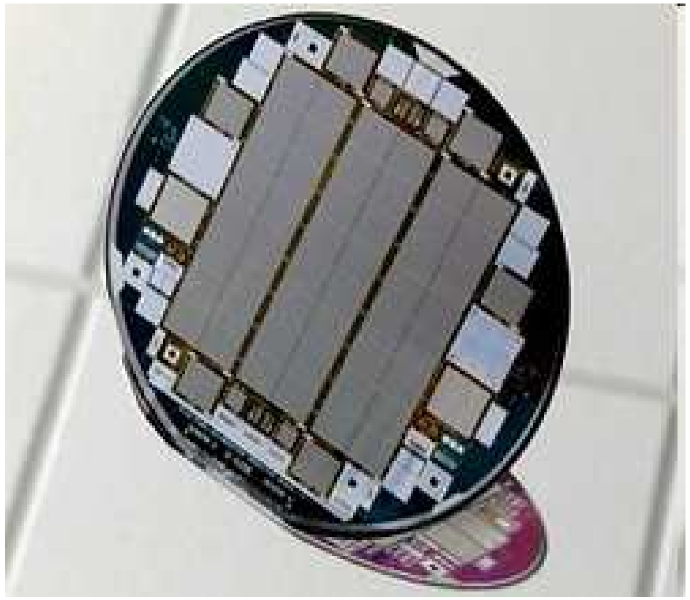
- Motivation
- New ICP etching tool at CiS
- 3D silicon radiation detector concept
- 3D detector processing sequence
- Conclusion

Motivation

- CiS has significantly contributed to sensor productions of various HEP experiments in past and present
    - ATLAS pixel, strips, IBL
    - CMS pixel, strips, CMS upgrade
    - ALICE
    - ...



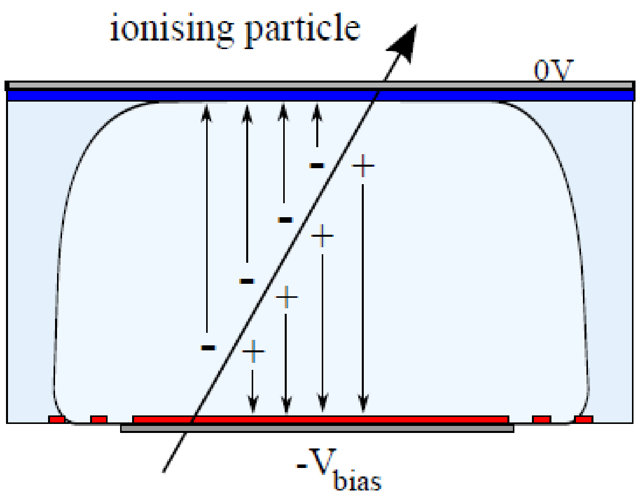


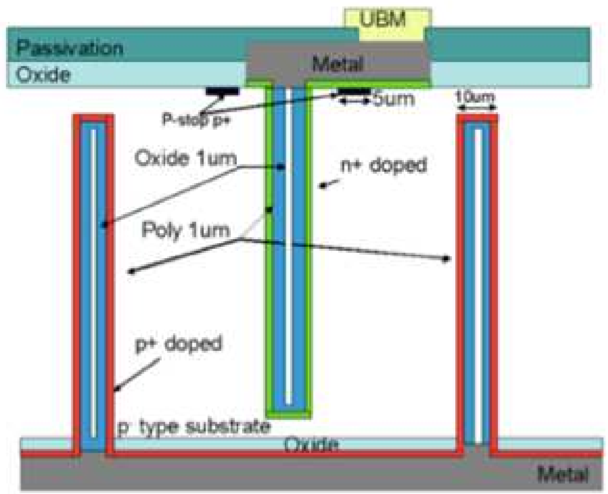


Motivation

- Advantages of HEP silicon detector based on 3D structures
  - Smaller electrode distances
    - Significantly lower depletion (& operation) voltage
    - Smaller drift distances
    - Higher charge collection efficiency after high irradiation
  - Reduced dead edge area possible

- CiS starts to explore feasibility of 3D silicon radiation detector production



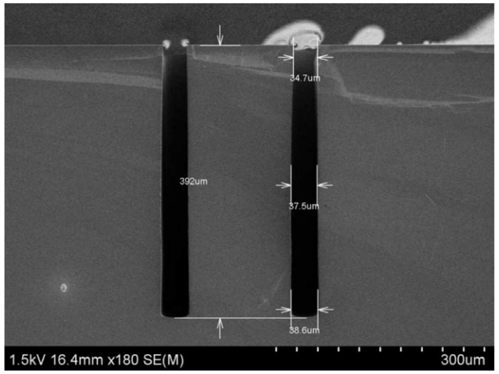


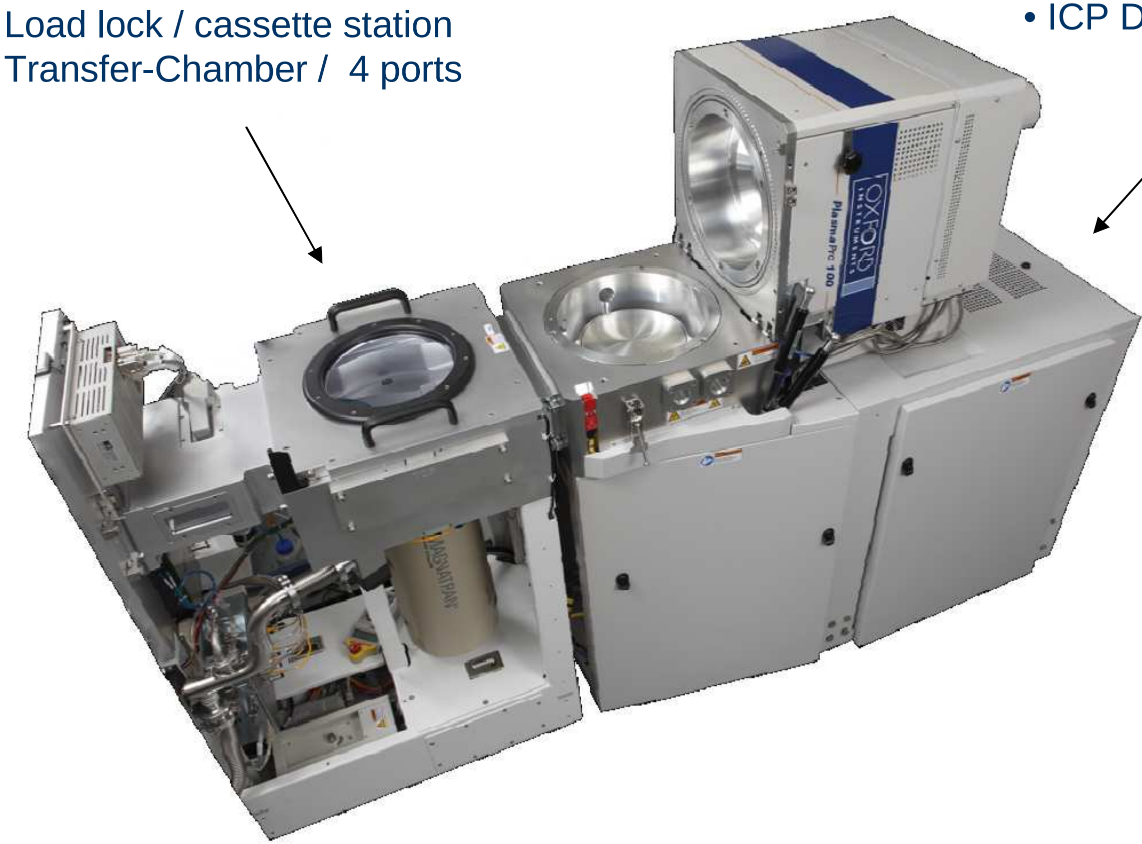
G. Pellegrini, M. Lozano, M. Ullán, R. Bates, C. Fleta, and D. Pennicard, Nucl. Inst. Meth.Phys. Res. A, 592 (2008) 38–43.

New ICP DRIE tool at CiS

Brooks Handler MMX
• Load lock / cassette station
• Transfer-Chamber / 4 ports

OIPT Plasma Pro Estrelas 100
• ICP DRIE etch chamber





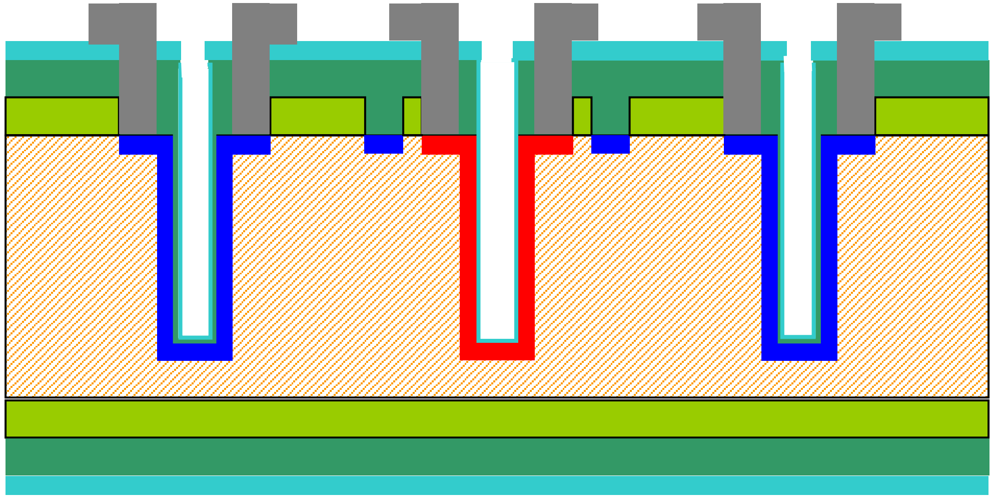
Demo etches in progress:
• very low tilt
• high etch rates
• very low scalloping depth
• AR up to 70

3D silicon radiation detector concept

- First CiS 3D silicon detector concept

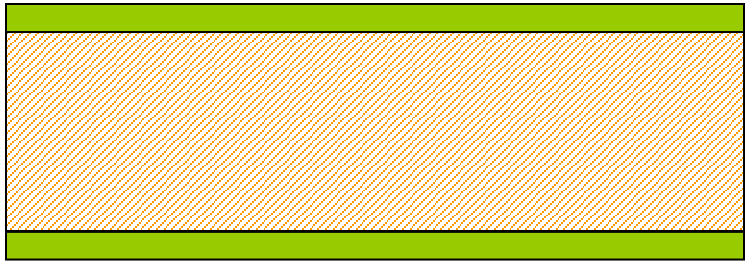
- Single side process
- Hole doping via solid source diffusion or plasma immersion ion implantation
- Passivation of hole inner surface by as-grown oxide, LPCVD oxide or LPCVD silicon nitride

- Control of hole inner surface carrier recombination by charge carrier lifetime measurements
- Method applied during processing after critical process steps



3D detector processing sequence

1) thermal oxidation

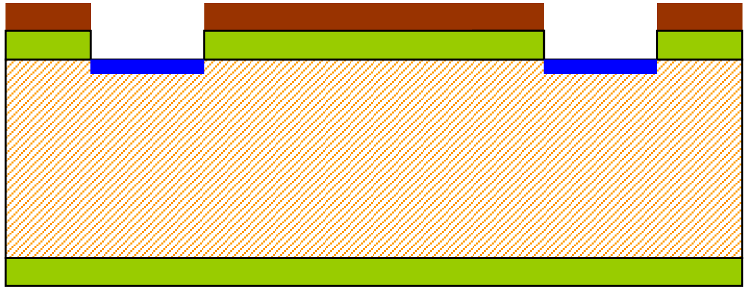


- n-type Si
- LPCVD oxide
- Resist
- LPCVD nitride
- thermal oxide
- p^+ doped Si
- n^+ doped Si
- aluminum

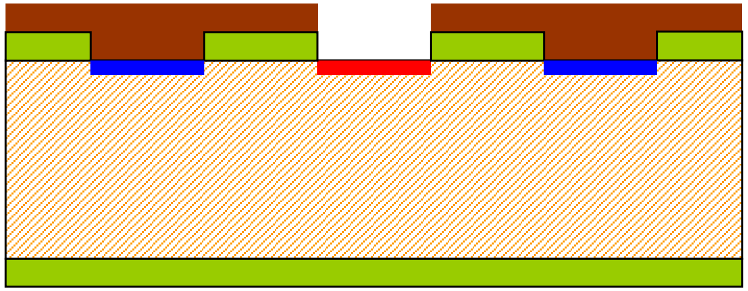
- Diffusion oxygenated FZ high resistivity n-type silicon
- Low surface recombination by thermal oxide

3D detector processing sequence

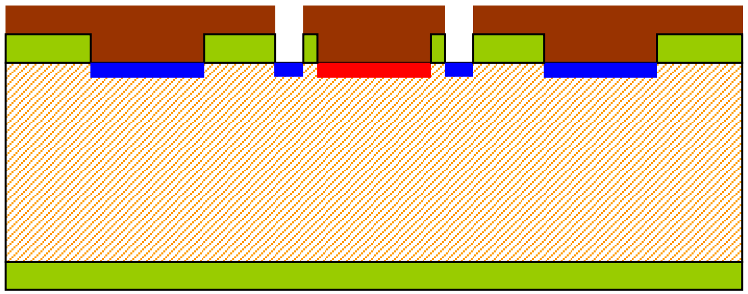
2) Litho 1 + boron implant

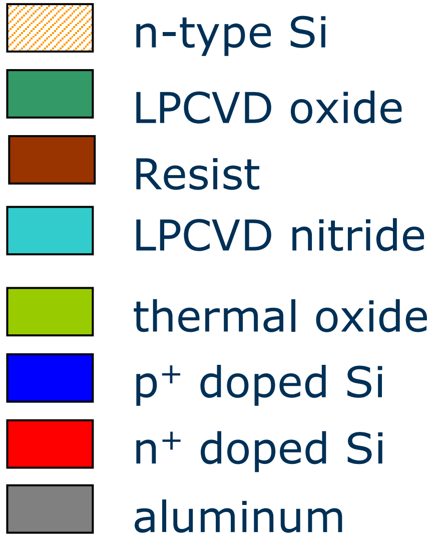


3) Litho 2 + phosphorous implant



4) Litho 3 + p-stop implant

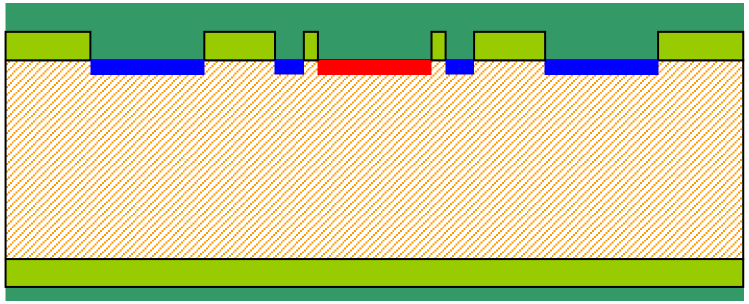


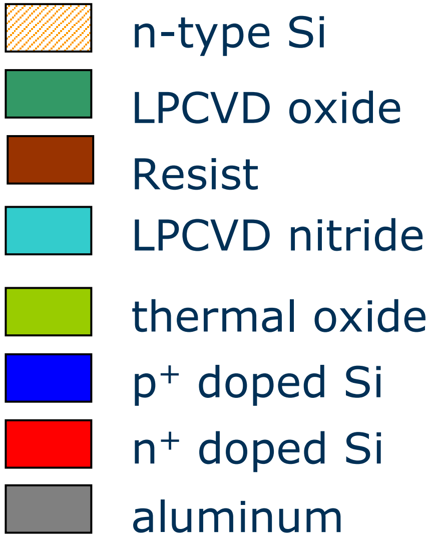


- Structuring and implantation of hole surroundings
- All dopings of planar surfaces by standard implantation

3D detector processing sequence

5) LPCVD oxide

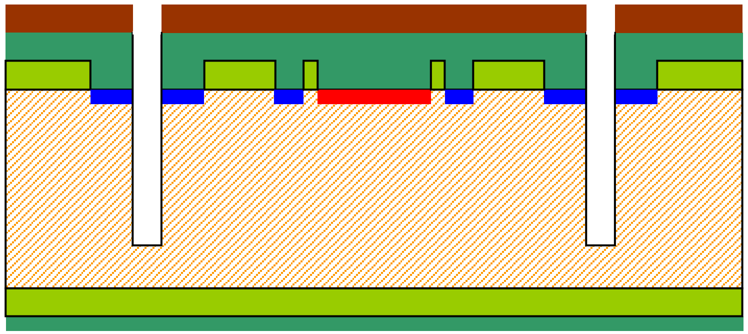




- Protection of structure by LPCVD oxide

3D detector processing sequence

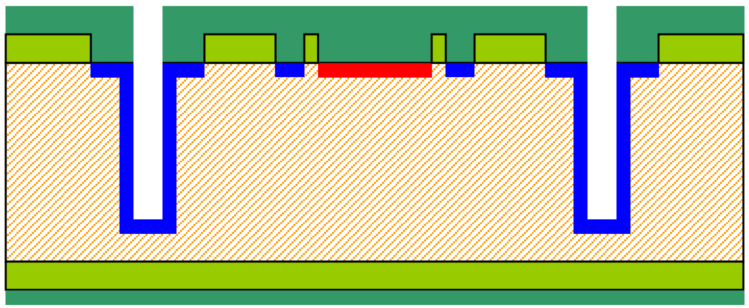
6) Litho 4 + DRIE



- Lithography
- Deep reactive ion etching of p-type holes

n-type Si
LPCVD oxide
Resist
LPCVD nitride
thermal oxide
p^+ doped Si
n^+ doped Si
aluminum

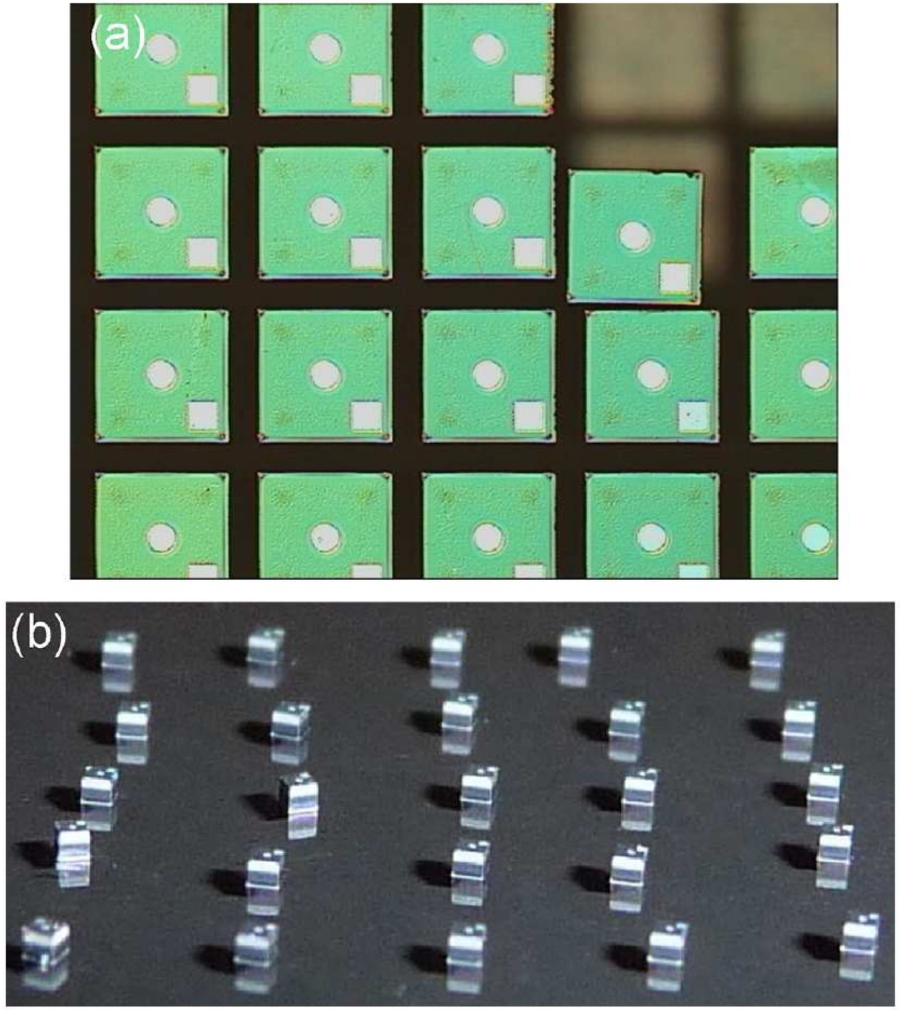
7) Boron doping (solid source diffusion or plasma immersion ion implantation)



- Doping of p-type holes
- Two possibilities
- Diffusion from solid source
- Plasma immersion ion implantation
- Both seem to be feasible and will be tested

3D detector processing sequence

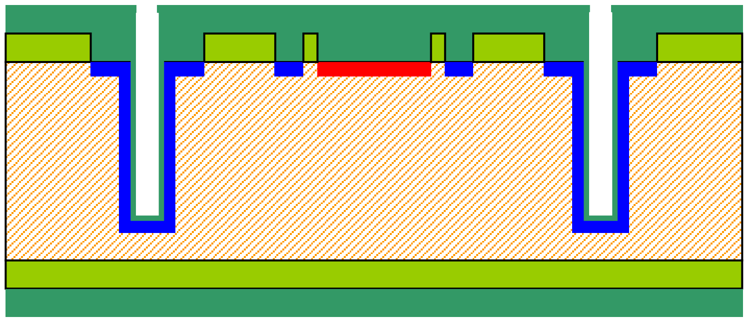
- Solid source diffusion recently successfully applied
- Example: cubic X-ray detectors
- Conformal doping of trenches (10µm width and up to 410µm depth)

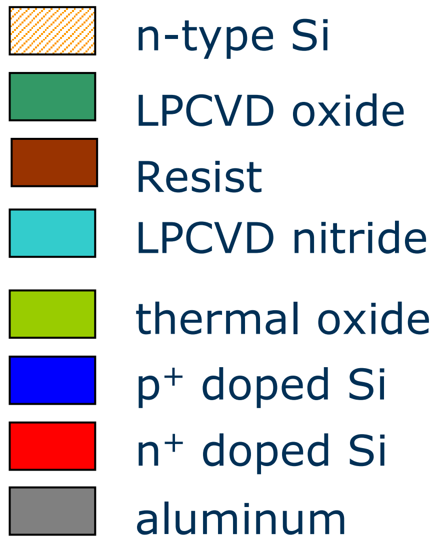


P. Norlin, O. Öberg, S. Junique, W. Kaplan, J. Y. Andersson, and G. Nilsson, “A cubic isotropic X-ray dose detector diode fabricated by DRIE of SOI substrates,” *Sensors and Actuators A: Physical, vol. 213, pp. 116–121, Jul. 2014.*

3D detector processing sequence

8) LPCVD oxide

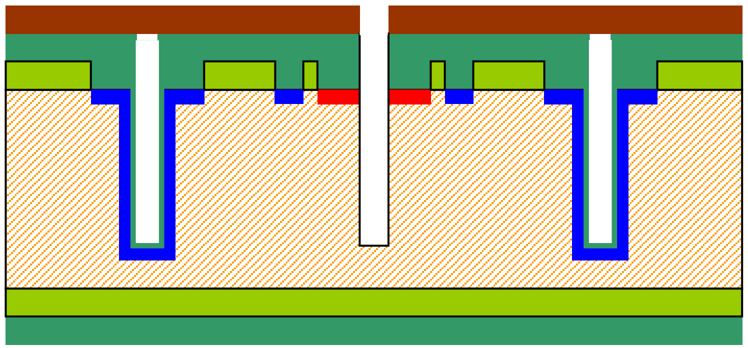




- Barrier against later phosphorous diffusion
- Oxidation of boron rich layer
- If not sufficient additional LPCVD oxide needed
- Surface recombination properties analyzed by charge carrier lifetime measurements

3D detector processing sequence

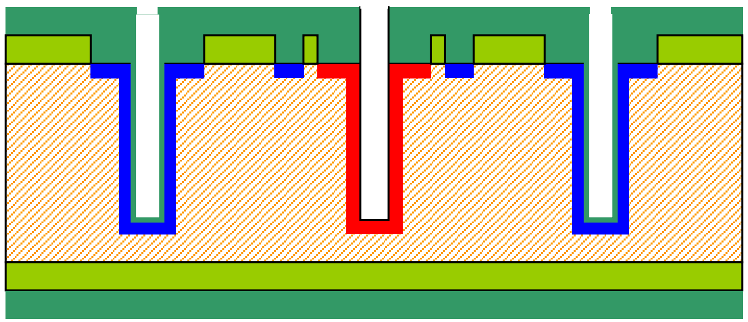
9) Litho 5 + DRIE



- Lithography
- Deep reactive ion etching of n-type holes

- n-type Si
- LPCVD oxide
- Resist
- LPCVD nitride
- thermal oxide
- p^+ doped Si
- n^+ doped Si
- aluminum

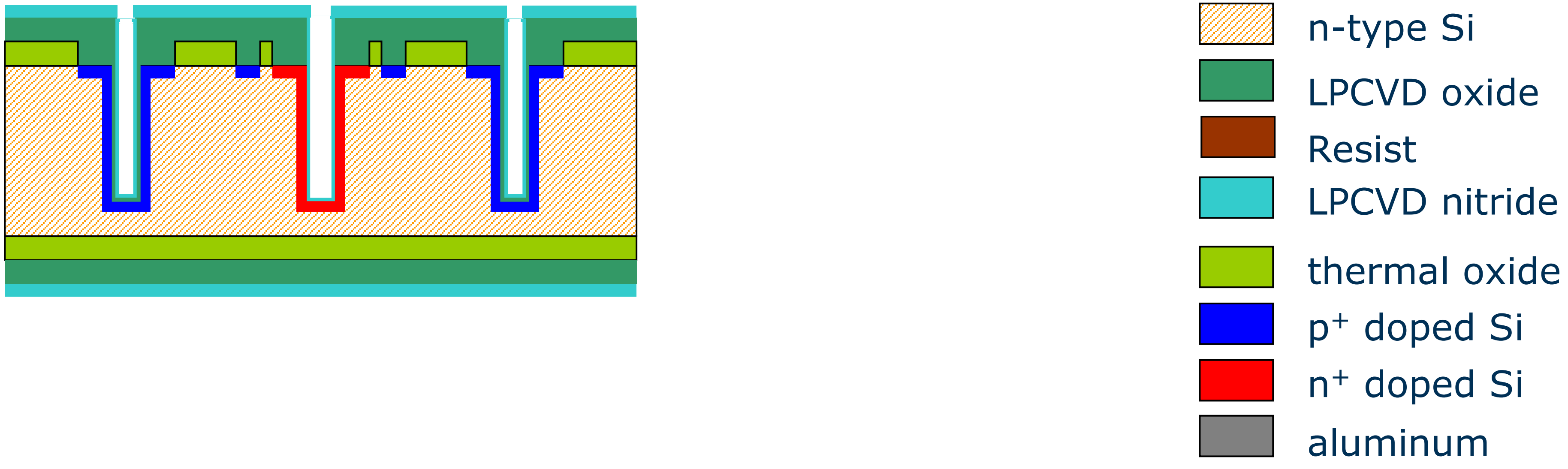
10) Phosphorous doping (solid source diffusion or plasma immersion ion implantation)



- Doping of n-type holes
- Again two possibilities
- Phophorous diffusion from solid source
- Plasma immersion ion implantation

3D detector processing sequence

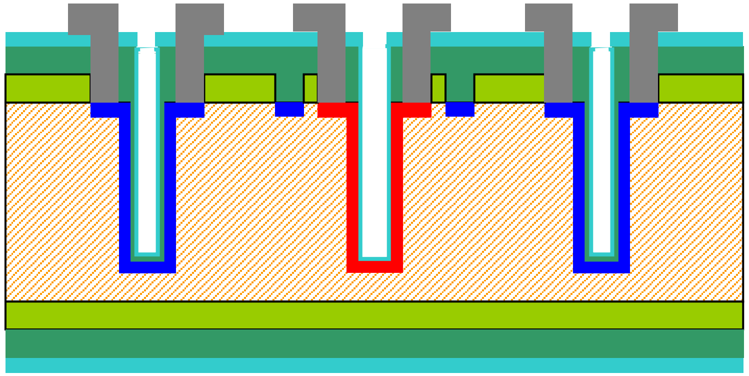
11) LPCVD nitride



- Final passivation of holes by LPCVD nitride
- Surface recombination properties analyzed by charge carrier lifetime measurements

3D detector processing sequence

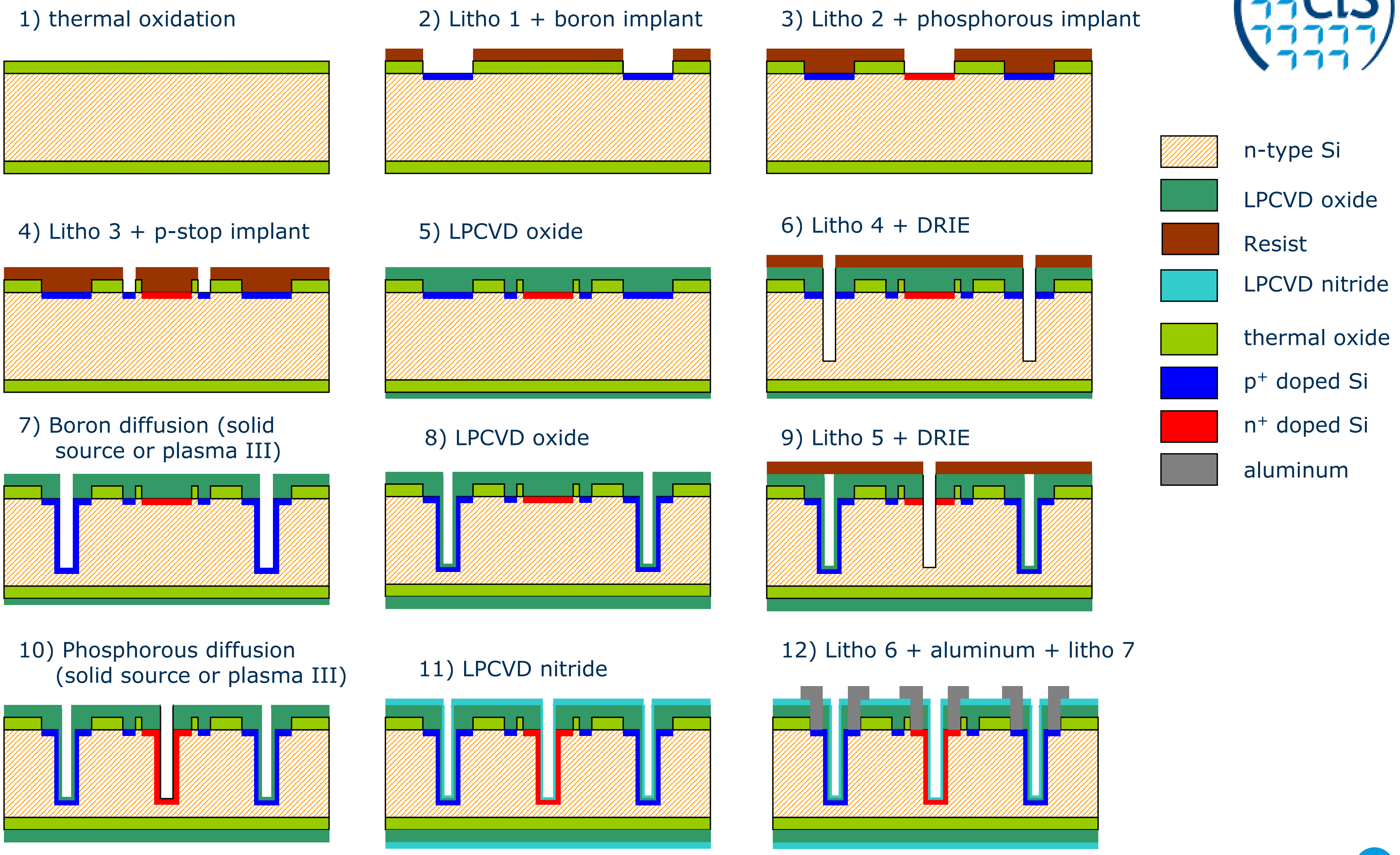
12) Litho 6 + aluminum + litho 7



n-type Si
LPCVD oxide
Resist
LPCVD nitride
thermal oxide
p^+ doped Si
n^+ doped Si
aluminum

- Lithography and etching to open contact holes in hole surrounding areas
- Aluminum contacts

3D detector processing sequence

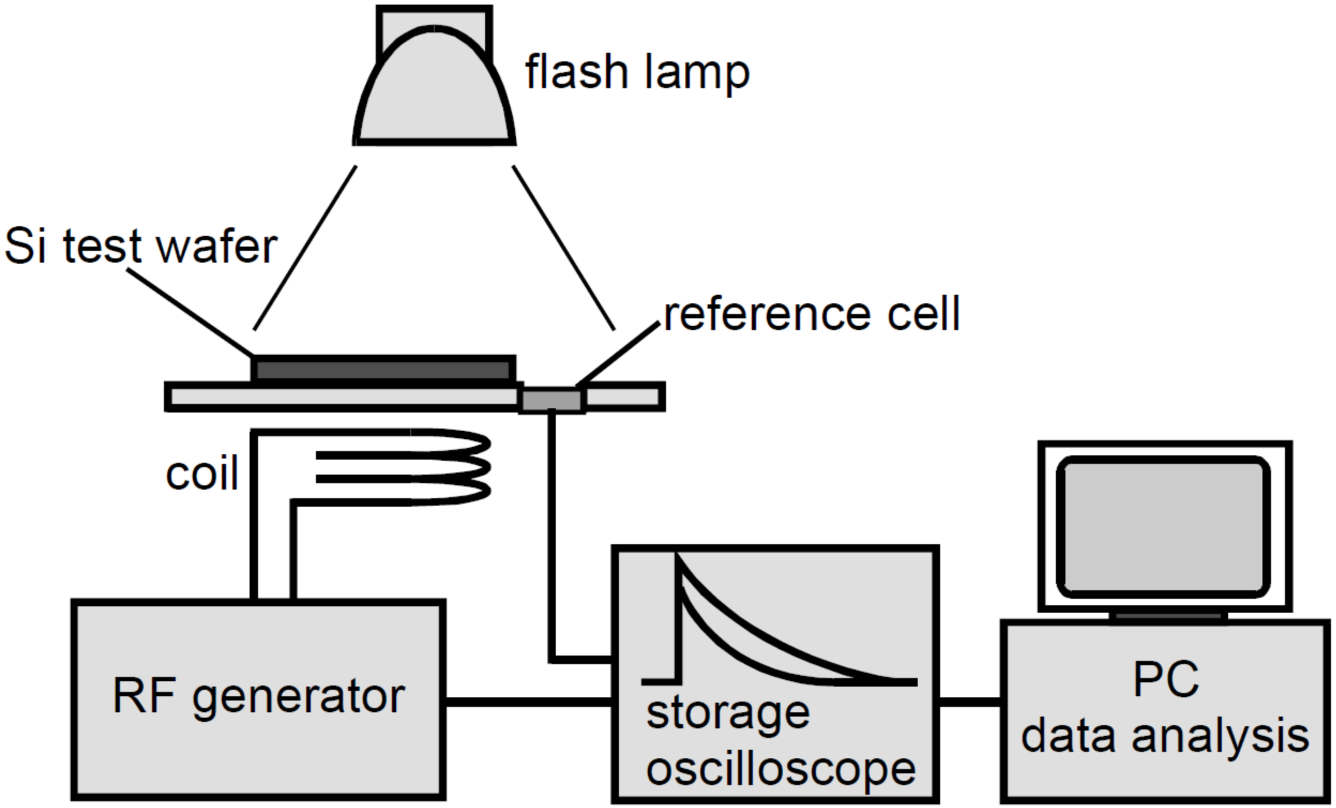


Conclusion

- CiS starts working on 3D silicon radiation detectors
- An ICP etching tool has been newly installed at CiS
- First 3D detector manufacturing concept of CiS presented
- Hole doping by solid source diffusion or plasma immersion ion implantation
- Control of hole inner surface properties by charge carrier lifetime measurements
- Manufacturing of first test structures planned in 2016
- Very early stage of our attempts, any comments or ideas are welcome!

Thank you for your kind attention!

Charge carrier lifetime measurements (QSSPC)



R. A. Sinton and A. Cuevas, "Contactless determination of current-voltage characteristics and minority-carrier lifetimes in semiconductors from quasi-steady-state photoconductance data," Appl. Phys. Lett., vol. 69, no. 17, pp. 2510–2512, 1996.

- Charge carrier lifetime quantifies recombination of electron hole pairs at inner hole surface
- Correlated to leakage current at hole surface