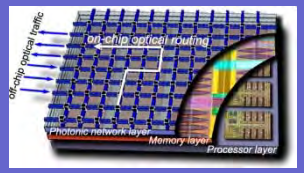


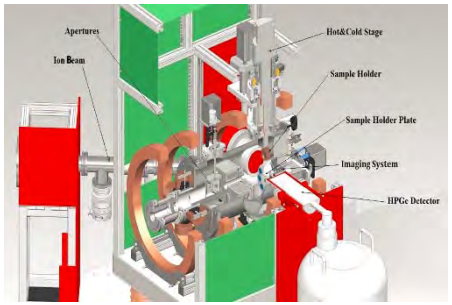
Slow Positron Spectroscopy – Applications to the Semiconductor Industry

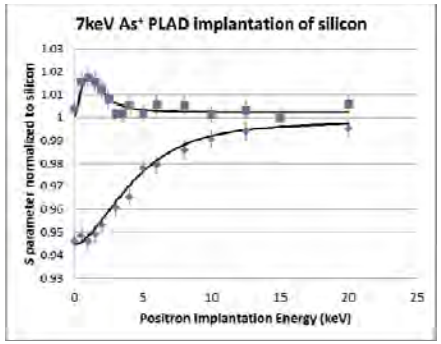
Dr. Andrew P. Knights

Professor

Department of Engineering Physics,

McMaster University, Canada.





McMaster University
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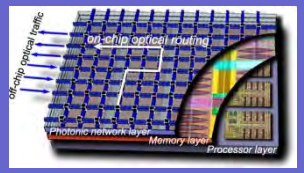




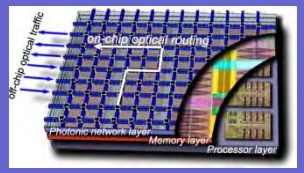
ION IMPLANTATION

EPITAXIAL GROWTH

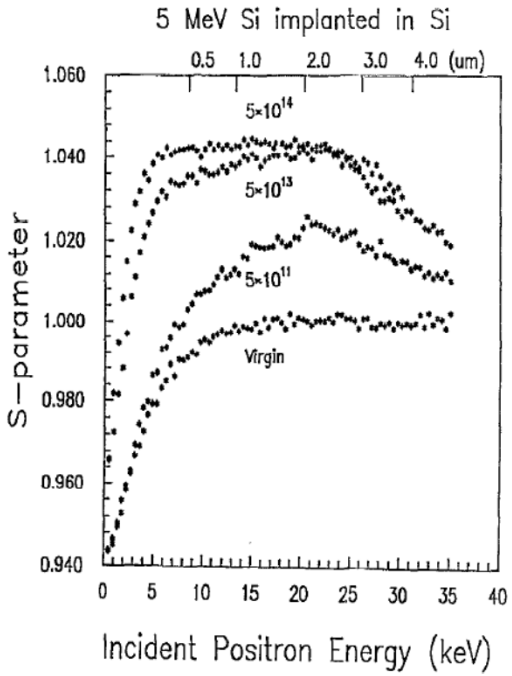
LOW-K DIELECTRICS

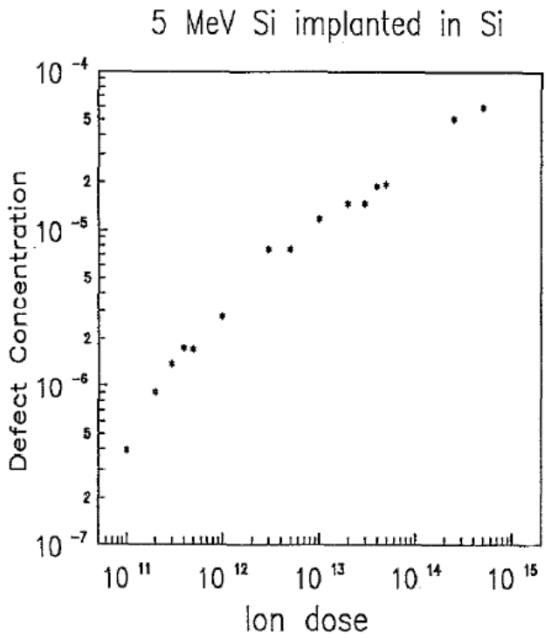
SILICON PHOTONIC DETECTORS

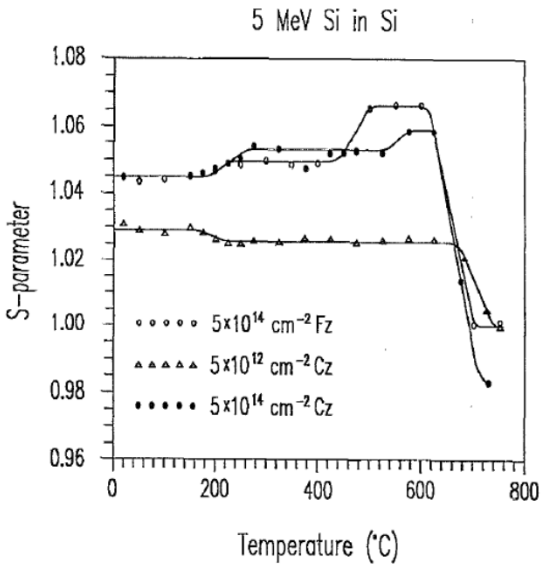
THE FUTURE



ION IMPLANTATION



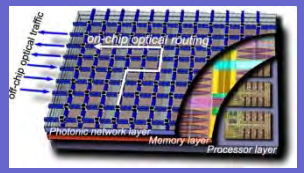




Defects in MeV Si-implanted Si probed with positrons

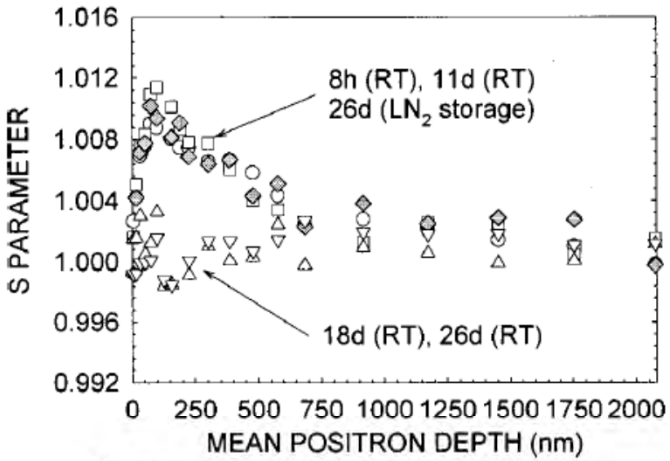
Bent Nielsen
Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973

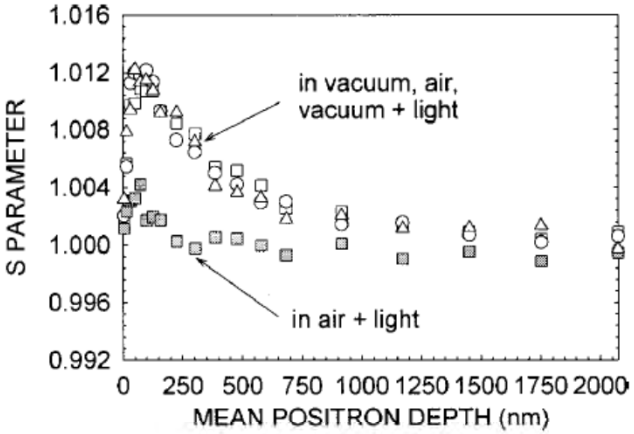
J. Appl. Phys. **74** (3), 1 August 1993

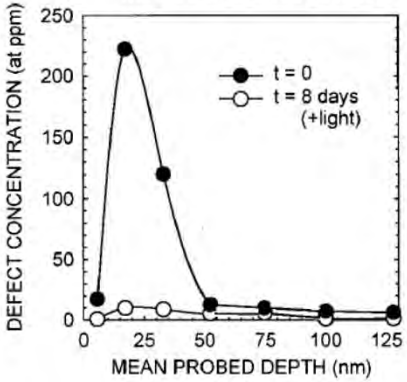




LOW ENERGY ION IMPLANTATION – DEFECT EVOLUTION







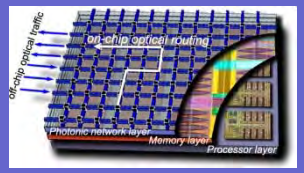
- Low energy implantation produces defects that interact with the surface.
- Under certain conditions it is possible to remove the defects.

Room-temperature evolution of vacancy-type damage created by 2 keV B + implantation of Si

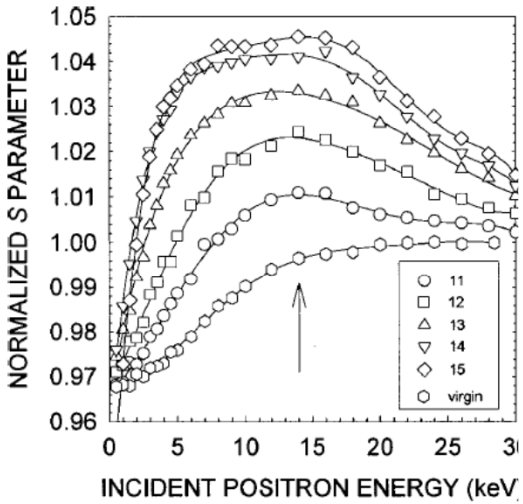
R. M. Gwilliam, A. P. Knights, C. P. Burrows, and P. G. Coleman

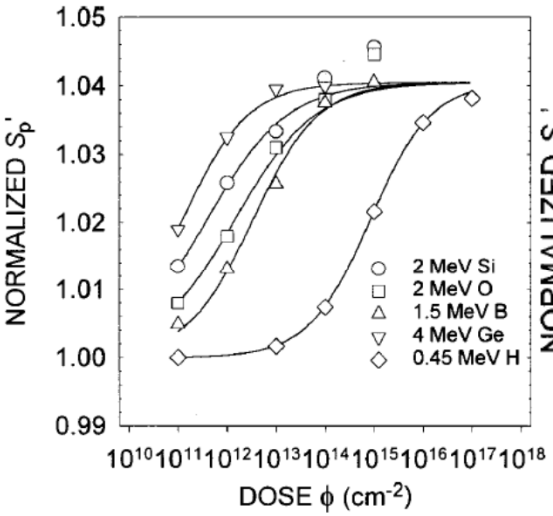
J. Vac. Sci. Technol. B 20(1), Jan/Feb 2002

McMaster University
Inspiring Innovation and Discovery



ION IMPLANTATION – DOSIMETRY





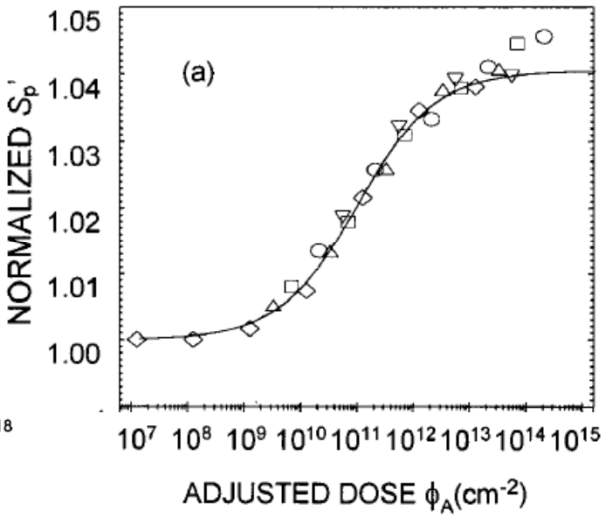


TABLE I. Ion dose normalization factors from TRIM simulations.

Ion species	Factor
0.45 MeV H^+	1.20×10^{-4}
1.5 MeV B^+	3.16×10^{-2}
2.0 MeV O^+	6.64×10^{-2}
2.0 MeV Si^+	2.01×10^{-1}
4.0 MeV Ge^{2+}	5.29×10^{-1}

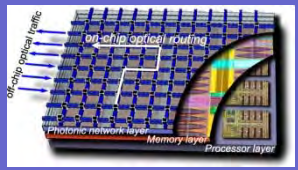
Simple expression for vacancy concentrations at half ion range following MeV ion implantation of silicon

P. G. Coleman, C. P. Burrows, and A. P. Knights

APPLIED PHYSICS LETTERS

VOLUME 80, NUMBER 6

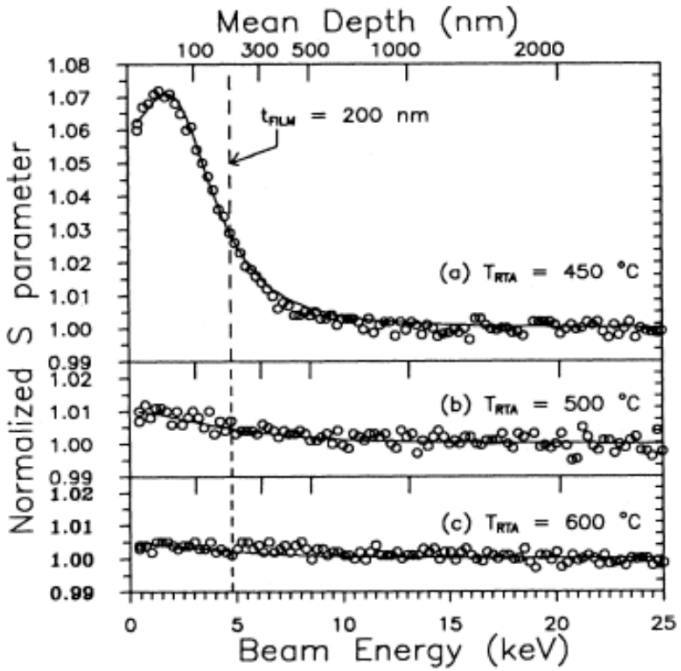
11 FEBRUARY 2002

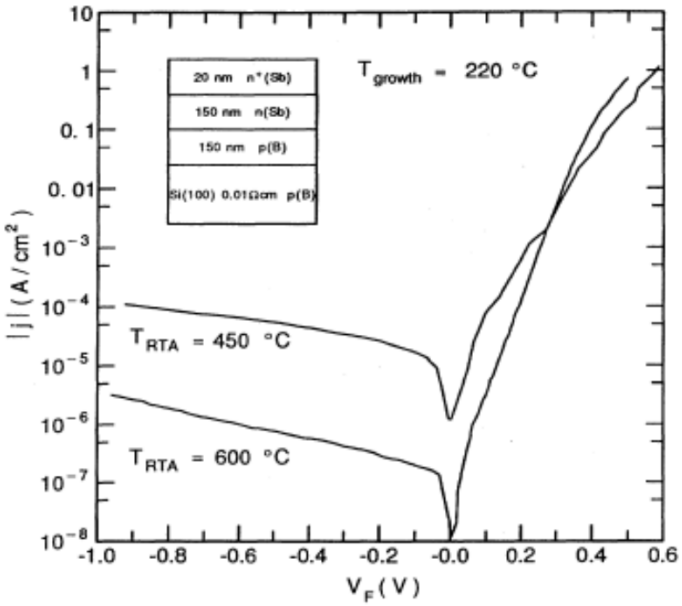


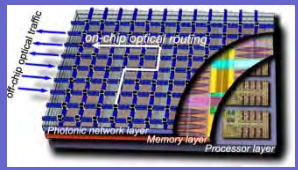
EPITAXIAL GROWTH

PHYSICAL REVIEW B VOLUME 48, NUMBER 8 15 AUGUST 1993-II

Distribution of point defects in Si(100)/Si grown by low-temperature molecular-beam epitaxy and solid-phase epitaxy





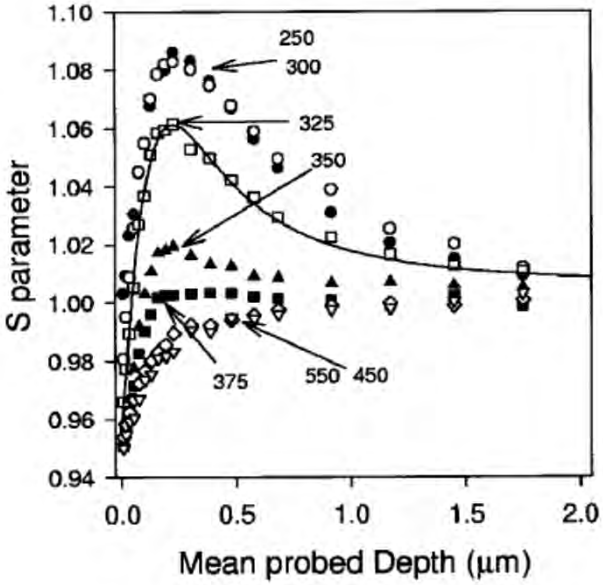


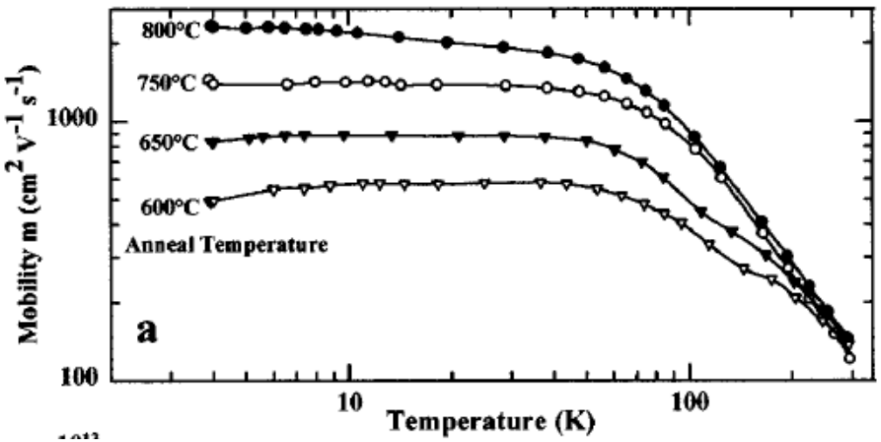
EPITAXIAL GROWTH

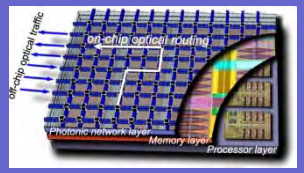
Growth temperature dependence for the formation of vacancy clusters in Si/Si 0.64 Ge 0.36 /Si structures

A. P. Knights, R. M. Gwilliam, B. J. Sealy, T. J. Grasby, C. P. Parry, D. J. F. Fulgoni, P. J. Phillips, T. E. Whall, E. H. C. Parker, and P. G. Coleman

JOURNAL OF APPLIED PHYSICS
VOLUME 89, NUMBER 1
1 JANUARY 2001







LOW-k DIELECTRIC MATERIAL

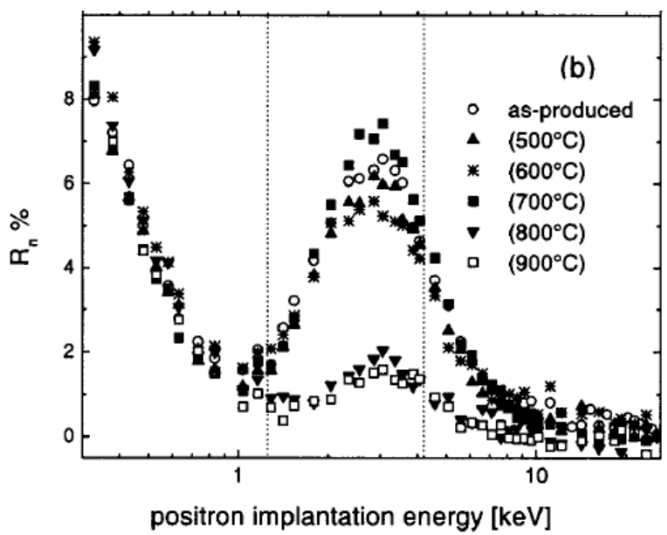
Porosity in low dielectric constant SiOCH films depth profiled by positron annihilation spectroscopy

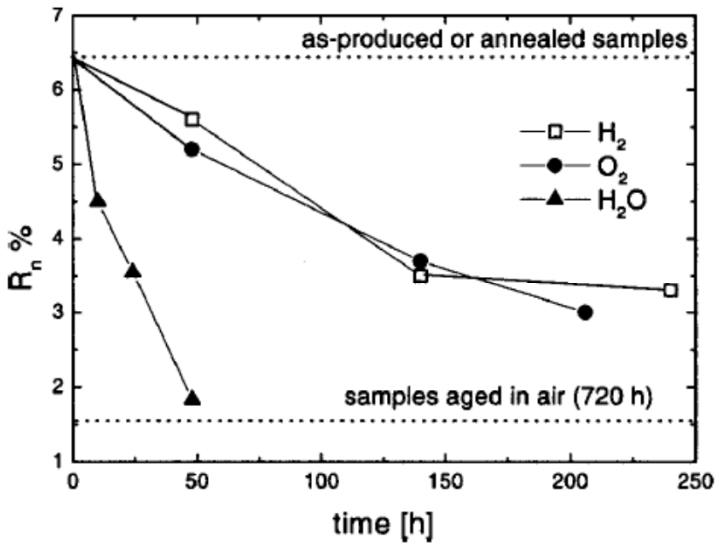
R. S. Brusa, M. Spagolla, G. P. Karwasz, A. Zecca, G. Ottaviani, F. Corni, M. Bacchetta, and E. Carollo

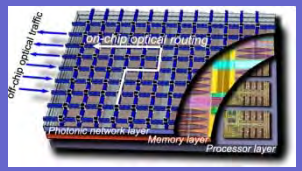
JOURNAL OF APPLIED PHYSICS

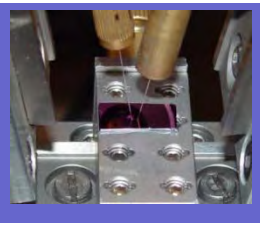
VOLUME 95, NUMBER 5

1 MARCH 2004



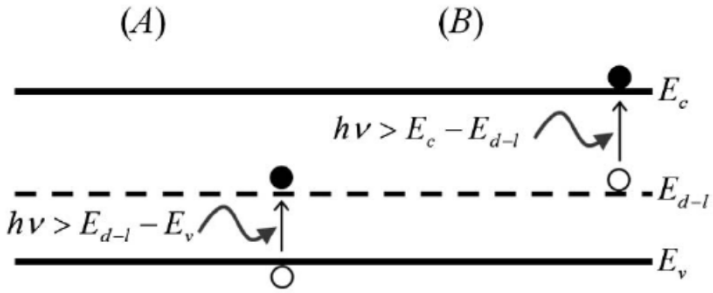


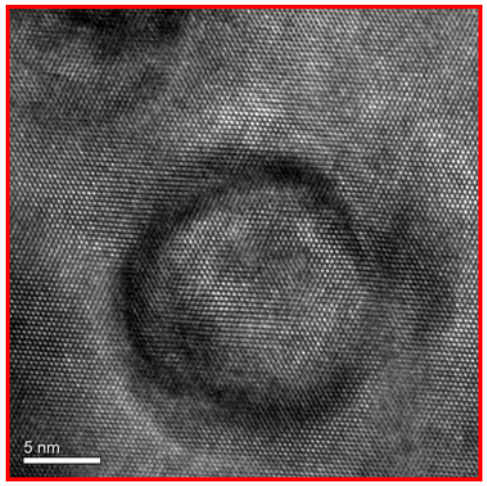




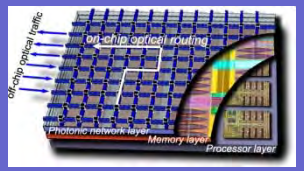
CASE STUDY – SILICON WAVEGUIDE DETECTORS

- Deep-level engineering (DLE) takes advantage of the ability of ion implantation to introduce bandgap states either structurally (eg. point defects) or through chemical doping
- DLE provides another ‘dimension’ in the design of silicon photonic circuits
- DLE was developed through a background of the study of defects and deep-levels and the use of ion implantation for doping and in particular implantation isolation of GaAs.





A nano-void imaged at McMaster using TEM – used for RI engineering and formed via He^+ implantation and annealing



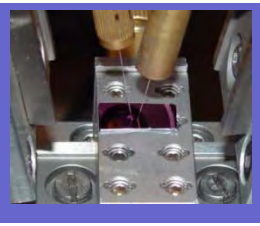
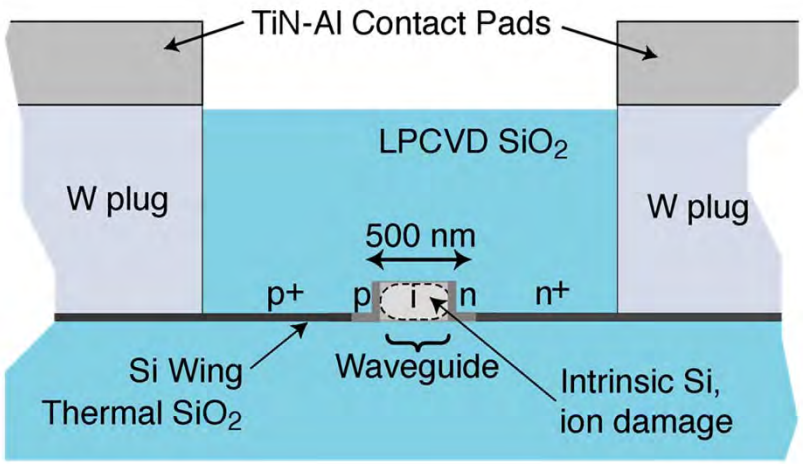
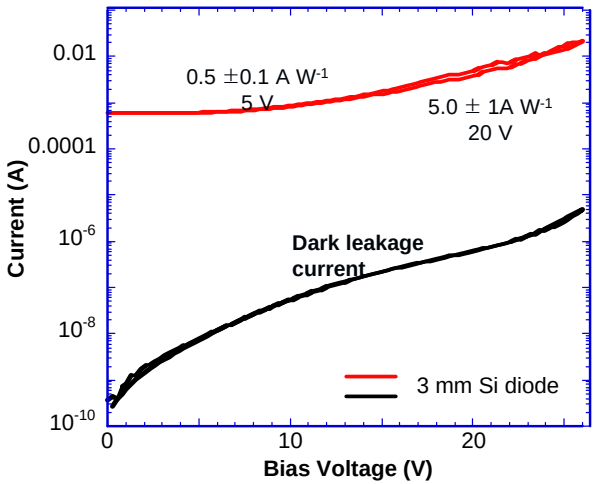
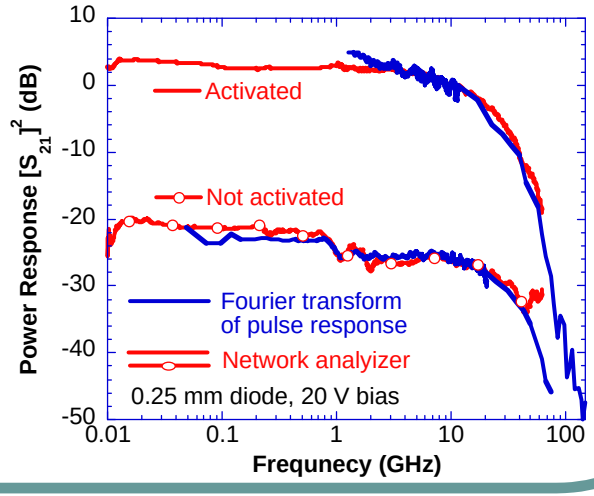


Photo current with
1 mW at 1539 nm

Benefit of being small







Slides courtesy of Mike Geis MIT Lincoln Labs

M.W.Geis *et. al.*, Optics Express **15**, 16886 (2007).

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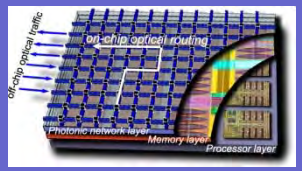
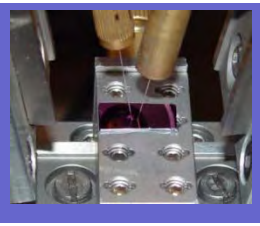
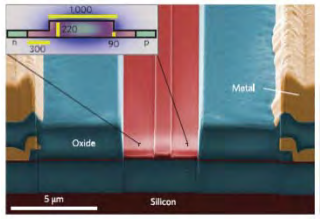
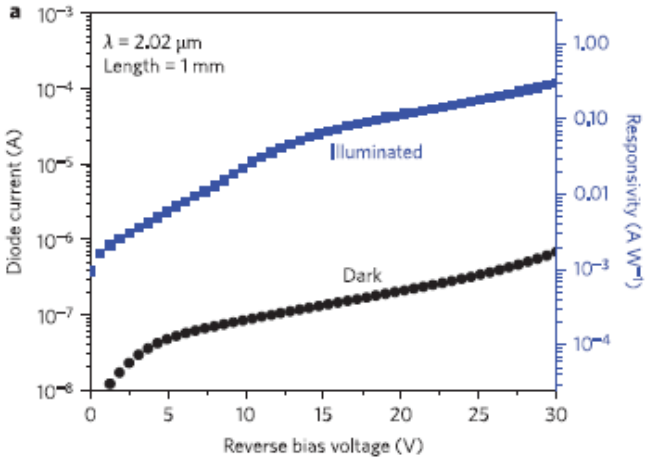
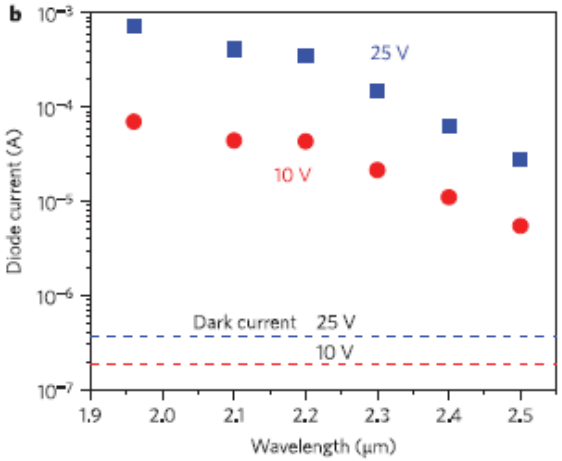




DLE detection at 2-2.5um

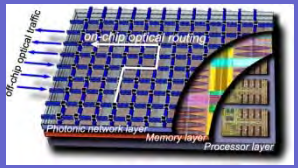


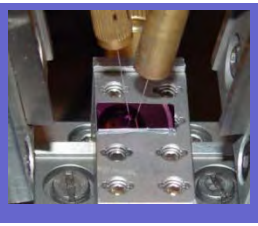




Ackert et al. Nature Photonics (2015)

- Significant effort is being expended on extending the wavelength range of optical communications
- Specifically, Thulium-Doped-Fiber-Amplifiers (TDFA) are now available for operation ~2um.
- DLE has no hard wavelength cut-off (unlike Ge for instance), and we recently demonstrated that DLE can be used at extended wavelengths.

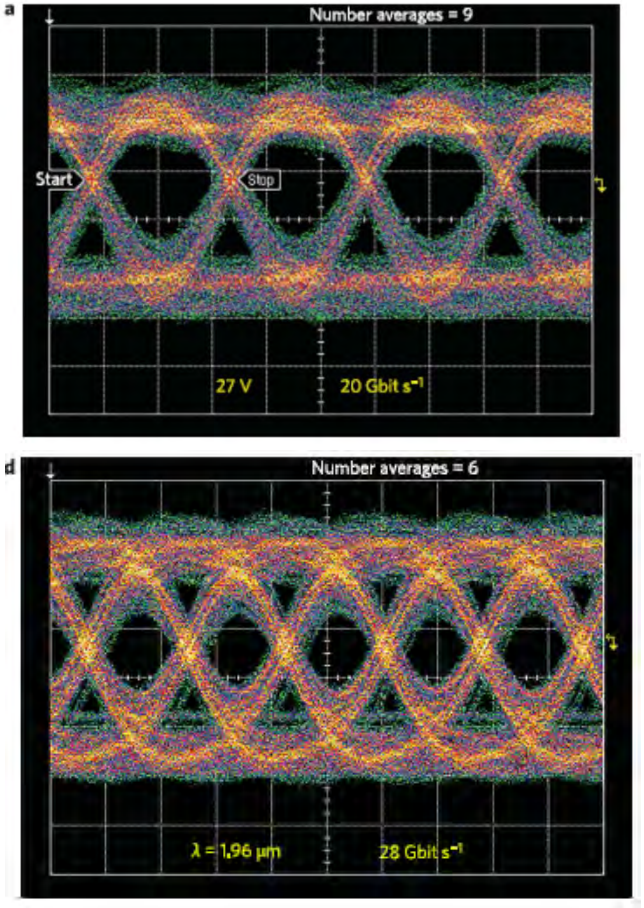




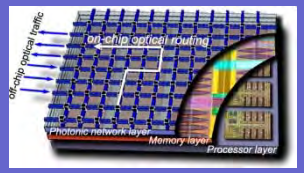
DLE detection at 2-2.5um

- The detectors operate error free at 20Gbps.
- Good eye diagrams observed at 28Gbps.
- 3dB bandwidth is ~15GHz.

Physics World May 2015

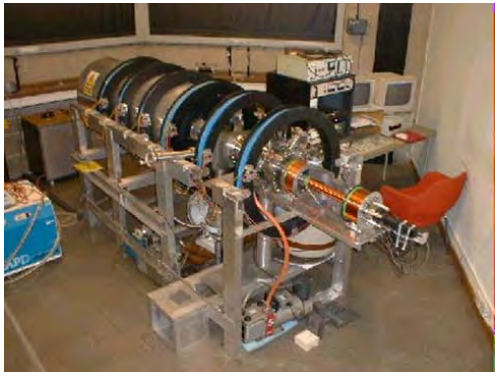


Ackert et al. Nature Photonics (2015)

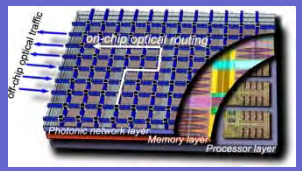


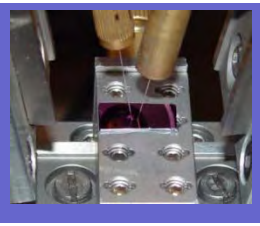


BENCH-TOP POSITRON BEAM



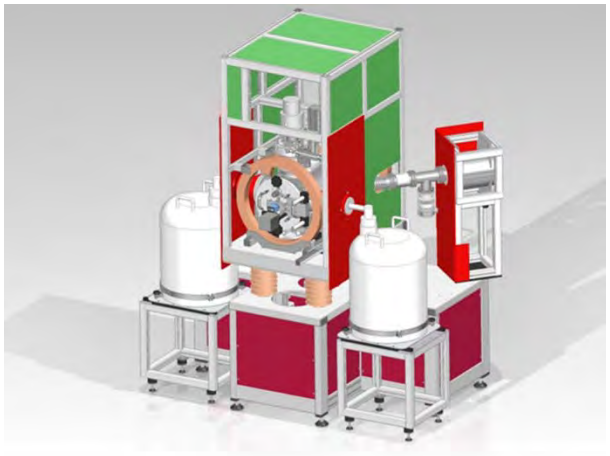
- We succeeded in developing a benchtop positron beam
- We modelled the footprint on previously adopted tools
- How could this fail to be adopted widely?

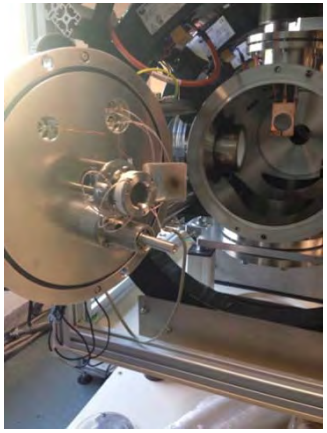


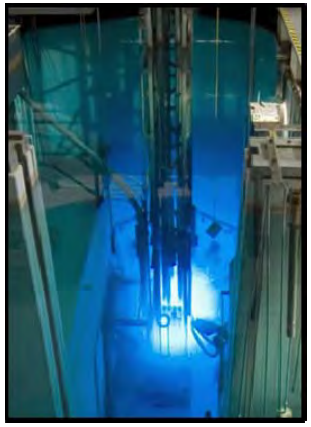


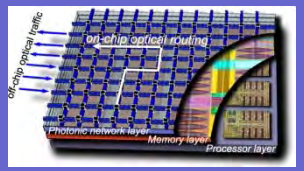
REACTOR-BASED POSITRON BEAM

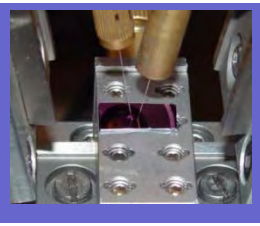
- Canada is soon to possess one of three reactor based, slow-positron beams.
- The current radioactive source experiments will benefit from a brightness enhancement of 3 orders of magnitude.
- The experimental chamber is designed to probe semiconductors (defects and fields).



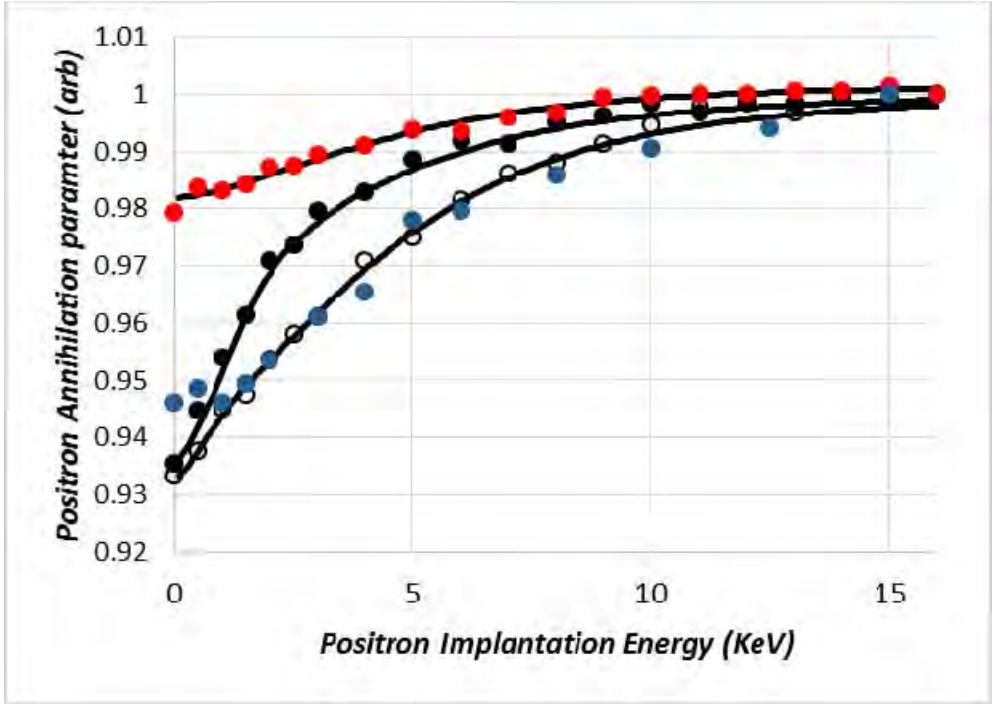




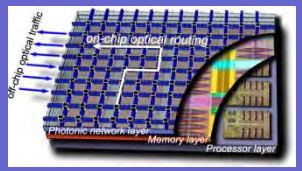


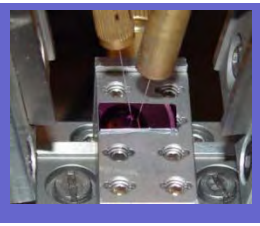


LOW ENERGY HELIUM IMPLANTATION

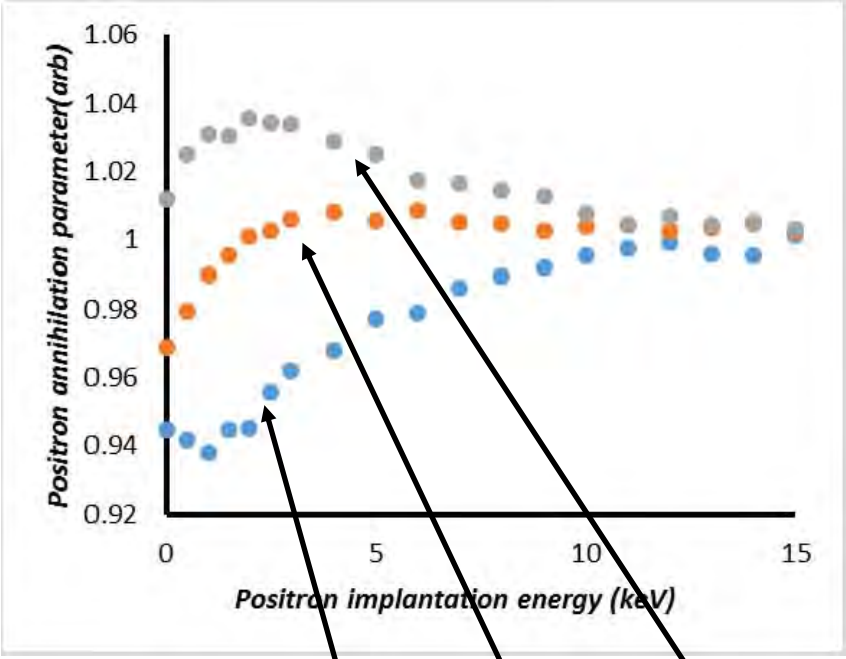


- The four spectra represent 3 samples implanted with He+ ions at 500eV to dose of 1e16cm^{-2}; plus an unimplanted sample.
- Three implants performed at RT (red); 250C (black) and 450C (open).
- A thin (10nm) highly defective layer forms at RT.
- A defect layer (~10^{18}cm^{-3}) ~80nm thick forms at 250C.
- No difference between virgin and 450C (lower limit defect concentration of 1e^{15}cm^{-3}).



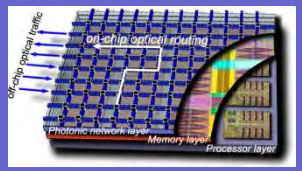


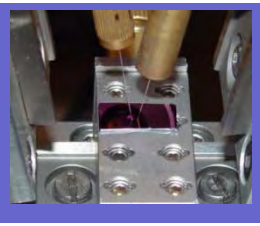
IN-SITU IMPLANTATION



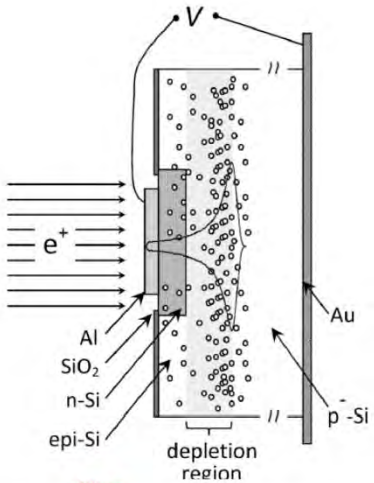
- Spectra of virgin Si; sub-amorphous implantation and amorphizing implantation (10keV Ar^+)

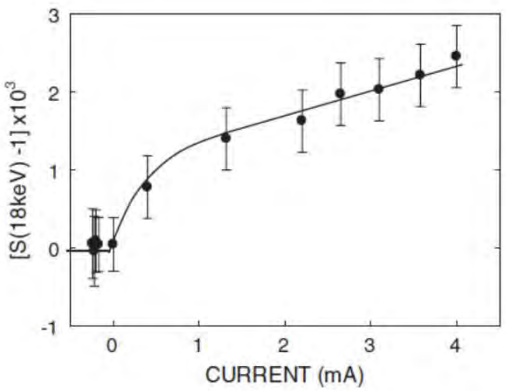
- A unique feature of the positron beam is the integration of an ion source.
- This permits in-situ implantation and analysis of defects.

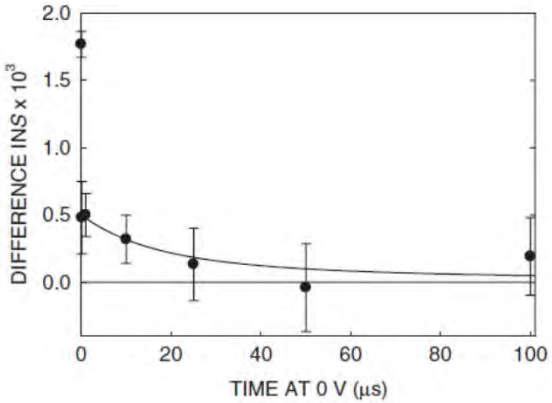


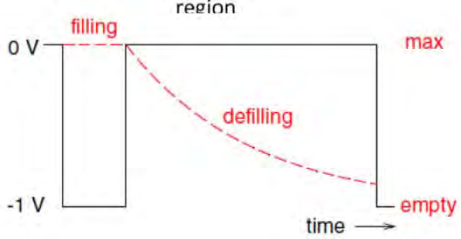


POSITRON DLTS – STRUCTURE AND ENERGETICS









- Coupled with a closed cycle He cold finger, we are able to implant damage at 30k and observe annealing
- We have developed dynamic study of defects: so-called positron-DLTS which probes the electronic trapping properties of vacancy-type defects.