

Micro-systems for Scalable QKD Components

Achievements

*Ryan Camacho

Ian Frank

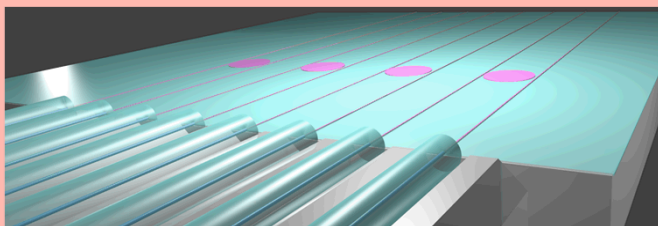
Matthew Tomes

Bruce Burckel

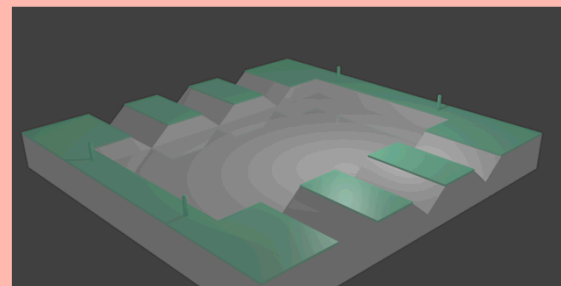
Ed Bielejec

Sandia Efforts

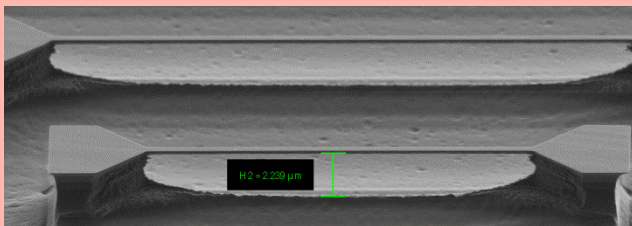
Demonstrate efficient (-1 dB) fiber – to – chip coupling, enabling quantum integration applications.



Develop simplified, scalable kinematic alignment techniques.



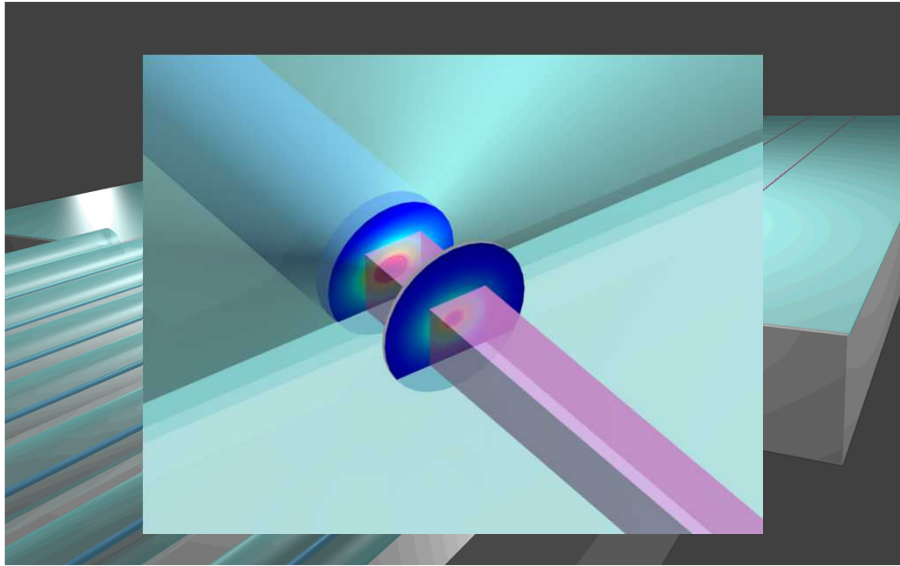
Develop targeted, deterministic ion implantation in diamond substrates. Supporting: Loncar, Englund, and Waks.



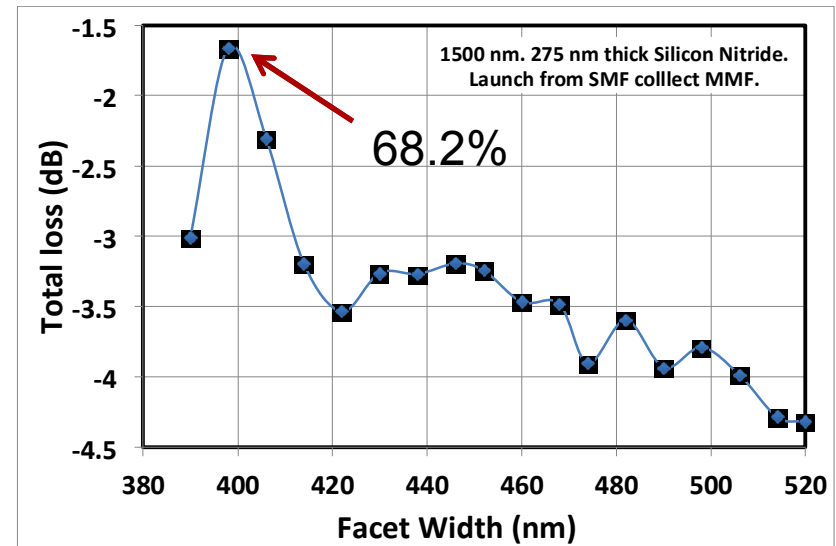
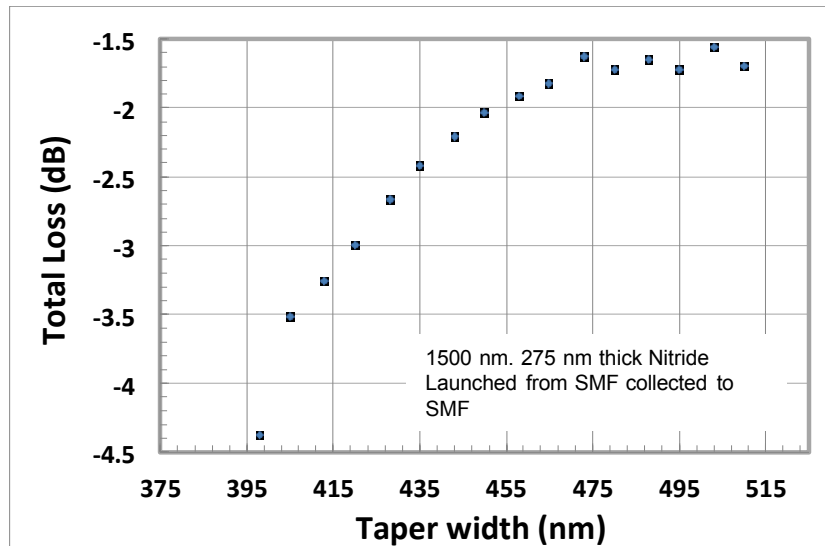
Deliver high quality, packaged, integrated resonators to Northwestern and UMBC teams.



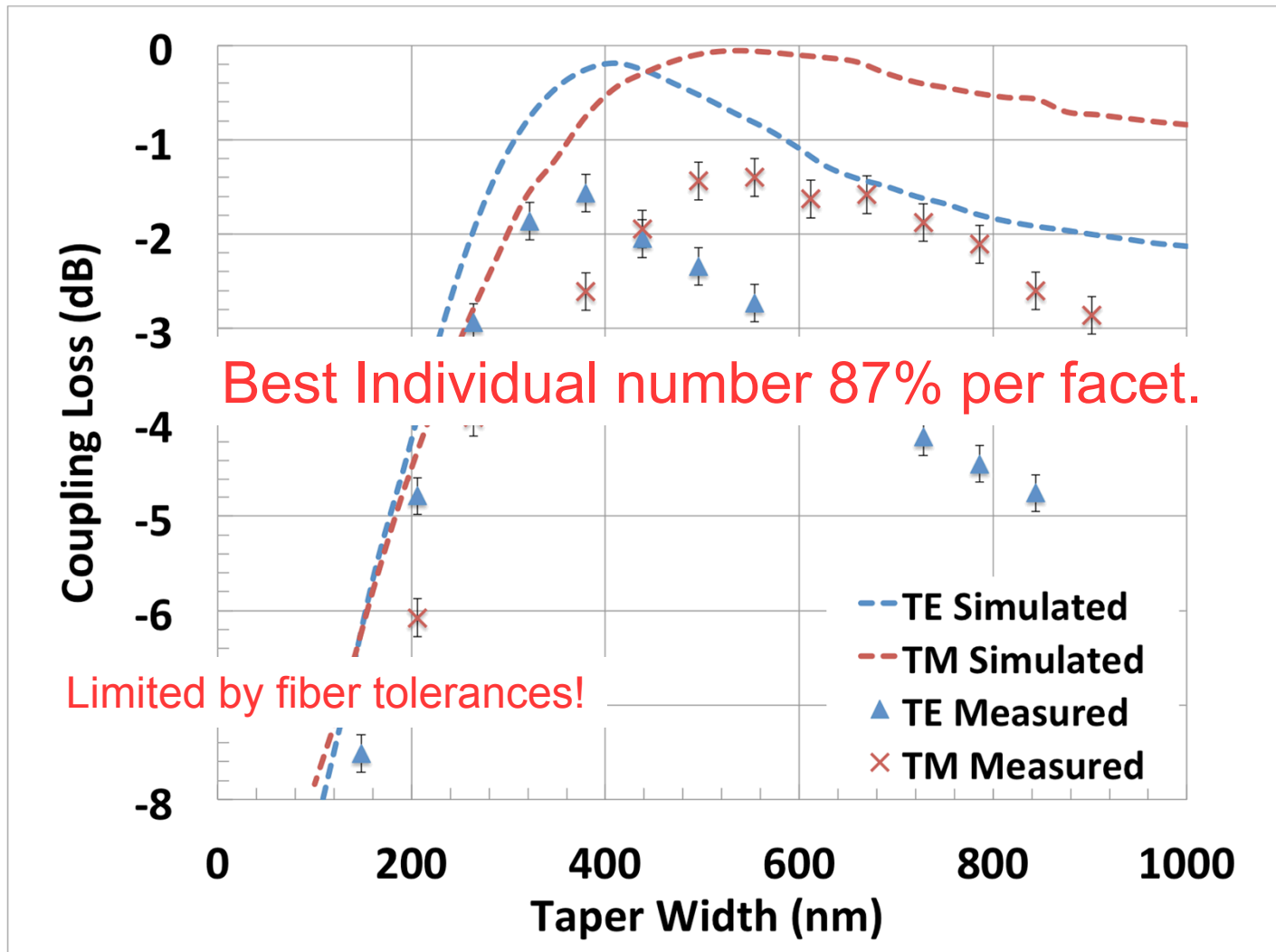
Efficient Fiber-to-chip Coupling



- Fiber and fiber arrays commercially available.
- Design on-chip devices to match available components.
- Do a six-axis alignment at sub-micron, milli-radian levels.
- **Our goal -1 dB Total loss.**

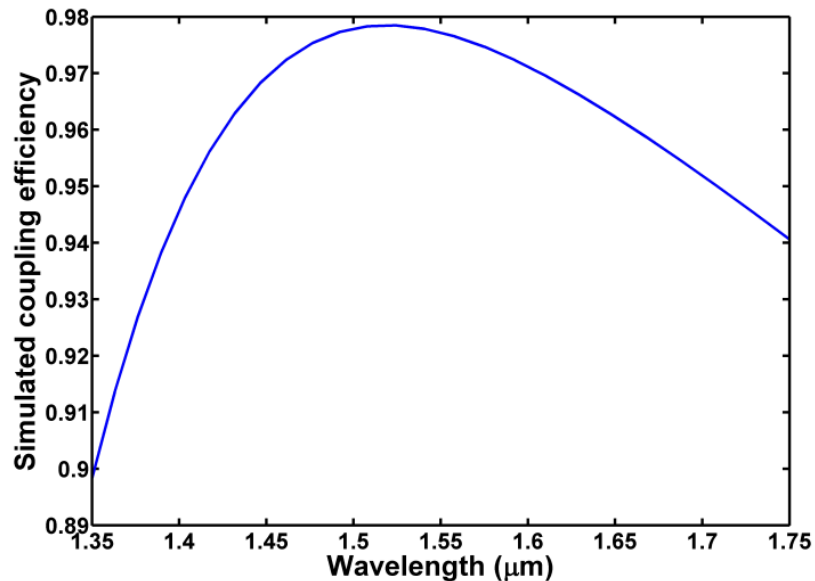


Advances in Fiber-to-chip coupling

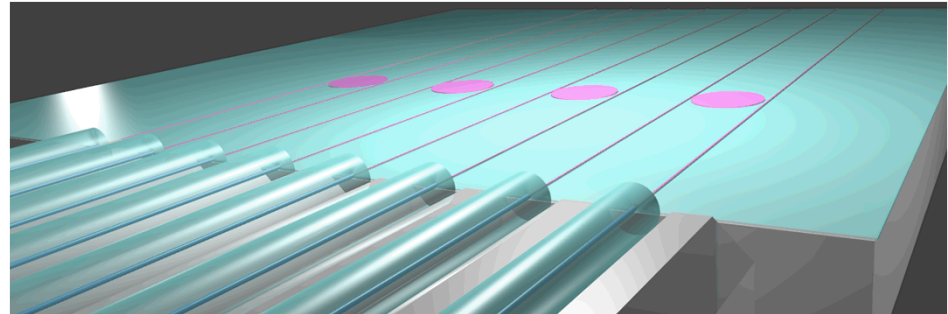


Bandwidth and multiple facets

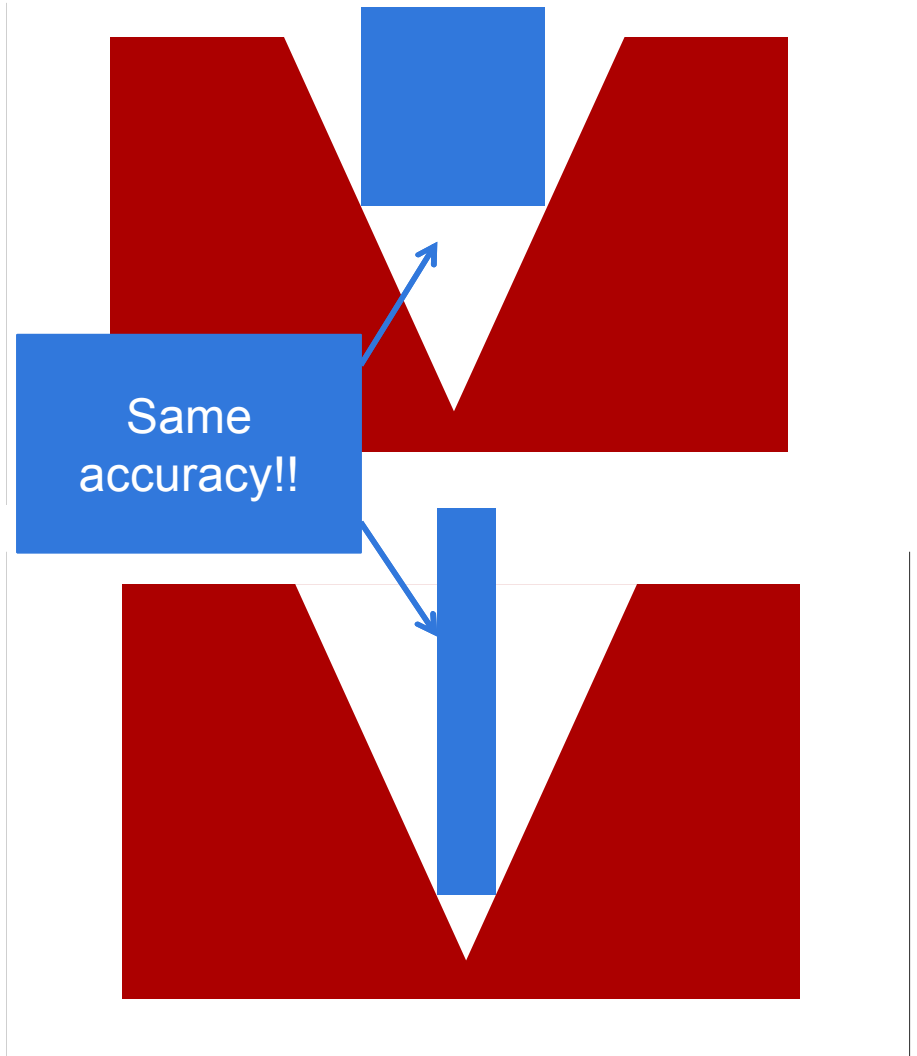
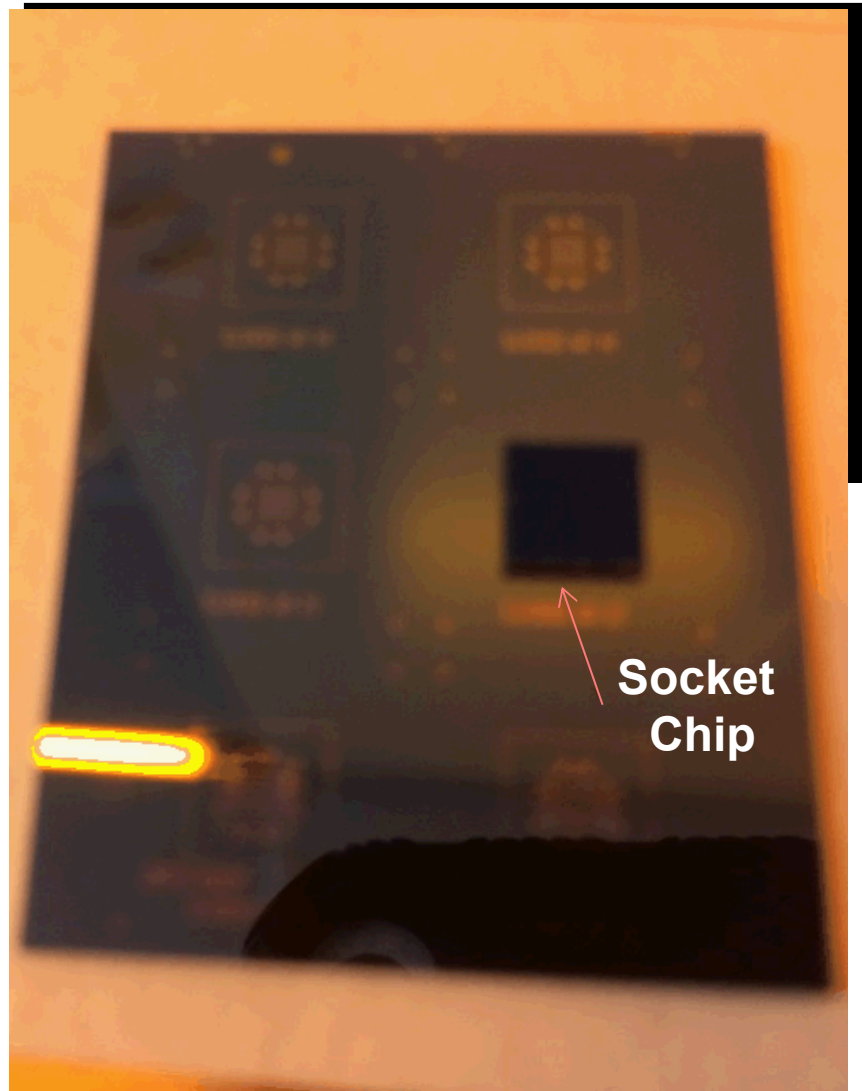
Note: will add experimental data to this.



Over 80% per facet across 4 channels for TE and TM.

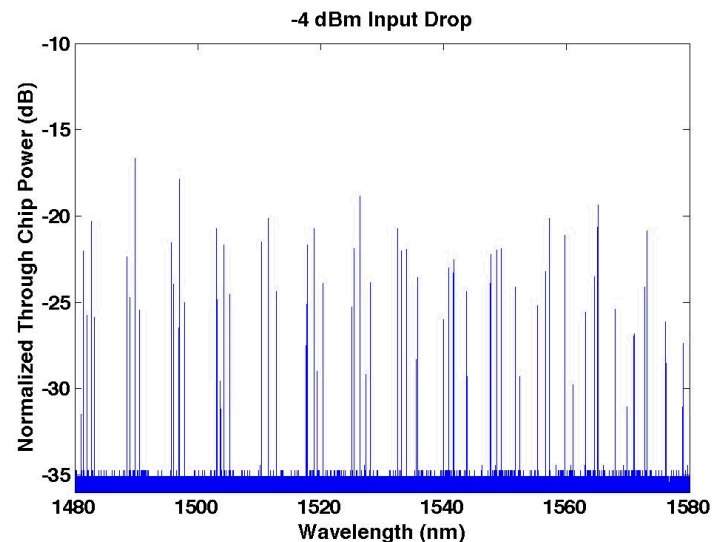
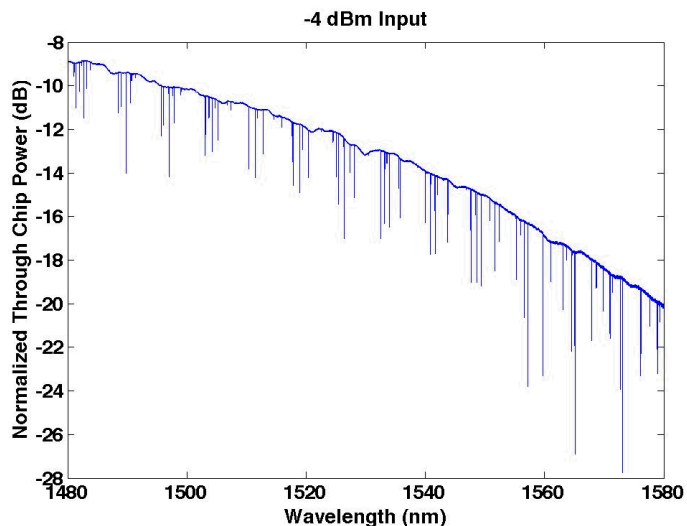


Kinematic Alignment Efforts



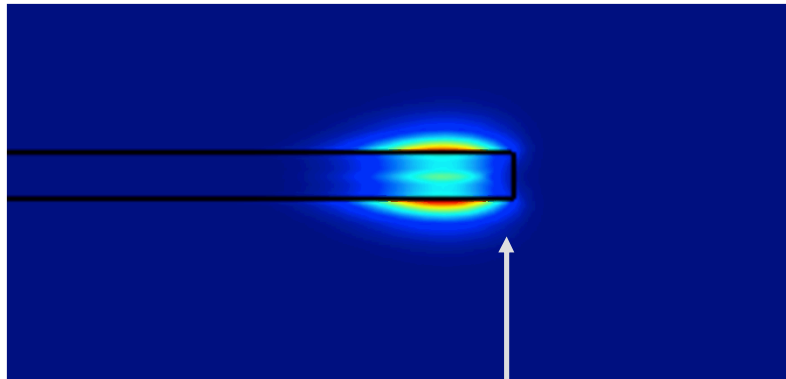
Devices for Northwestern

- Non-linear switching. Requested specifications:
 - Maximum on chip loss: 7 dB
 - Maximum off-chip loss for the through port: 8 dB
 - Maximum off-chip loss for the drop port: 6 dB
 - Q_s on the order of 10^6
- Delivered device 1 – damaged during shipping.
- Delivered device 2 –
 - -9 dB total efficiency at 1500 nm compared to specified -13 dB and -15 dB.
 - $Q_s > 500,000$ – nonlinearity makes it hard to measure.
 - Not tested yet...

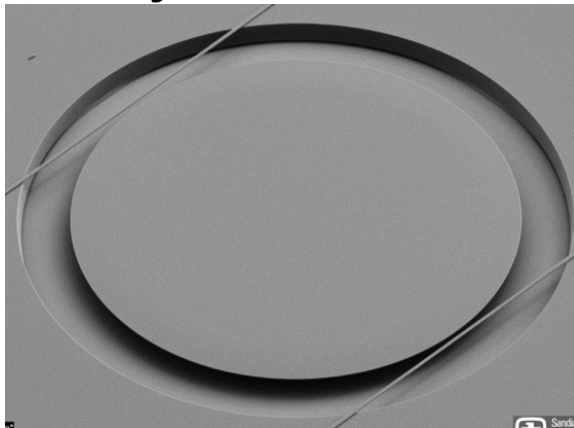


Devices for UMBC

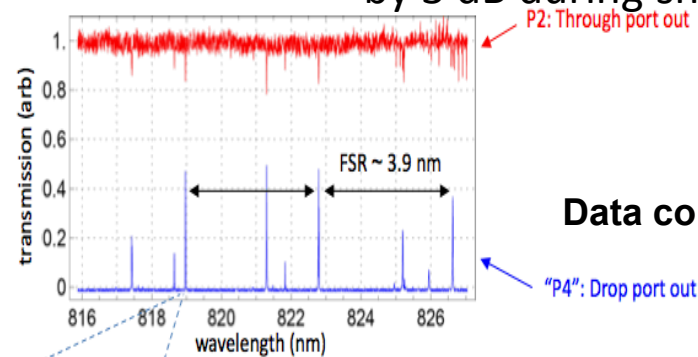
Phase shifting micro-disks



Use of vertical polarization mode allows for up to 30% of the energy density to be located in Xe



- Requested specifications:
 - Resonance at 823 nm
 - $Q > 100,000$
- Delivered:
 - Resonances with FSR of 3.9 nm – thermally tunable to exact Xe line.
 - $Q > 140,000$
 - Coupling efficiency decayed by 3 dB during shipping.



Data courtesy of T. Pittman

Ion Beam Implantation for Color Center Formation in Diamond

Goal – Deterministic single color center formation in diamond for single photon sources and quantum memory. Key issues:

- 1.) Yield – need to determine the yield for shallow color centers
- 2.) In-situ detection – need to develop the ability to detect single ion strikes in diamond

Focused Ion Beam Implantation Capability at SNL

- Four accelerators with focused ion implantation capability
- Range of ion species from H to Bi
- Highlight the **nanolimplanter (nl)**

hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122															neon 10 Ne 20.180	
sodium 11 Na 22.990	magnesium 12 Mg 24.305															argon 18 Ar 39.948	
potassium 19 K 39.098	calcium 20 Ca 40.078															krypton 36 Kr 83.80	
rubidium 37 Rb 85.468	strontium 38 Sr 87.62															xenon 54 Xe 131.29	
cesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 ★															
francium 87 Fr [223]	radium 88 Ra [226]	89-102 ★ ★															

Green – demonstrated at other labs

Purple – demonstrated at SNL

Yellow – attempting at SNL

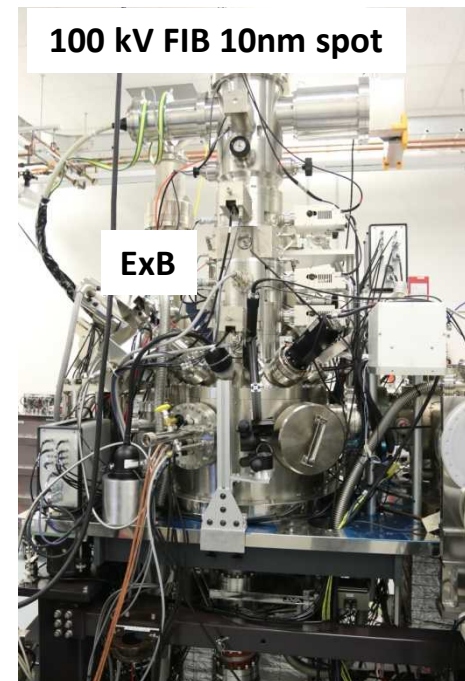
scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	paladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
lanthanum 57 La 138.905	cerium 58 Ce 140.12	praseodymium 59 Pr 140.908	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europtium 63 Eu 151.964	gadolinium 64 Gd 157.25	terbium 65 Tb 158.925	dysprosium 66 Dy 162.50	holmium 67 Ho 164.930	erbium 68 Er 167.259	thulium 69 Tm 168.930	ytterbium 70 Yb 173.04		
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]		

B	C	N	O	F	Ne
10.811	12.011	14.007	15.999	18.998	20.180
13	14	15	16	17	18
Al	Si	P	S	Cl	Ar
26.982	28.086	30.974	32.065	35.453	39.948
Ga	Ge	As	Se	Br	Kr
69.723	72.61	74.922	78.96	79.904	83.80
In	Sn	Sb	Te	I	Xe
114.82	118.71	121.76	127.60	126.90	131.29
Tl	Pb	Bi	Po	At	Rn
204.38	207.2	208.98	[209]	[210]	[222]
Uun	Uuu	Uub	Uuq		
[271]	[272]	[273]	[289]		

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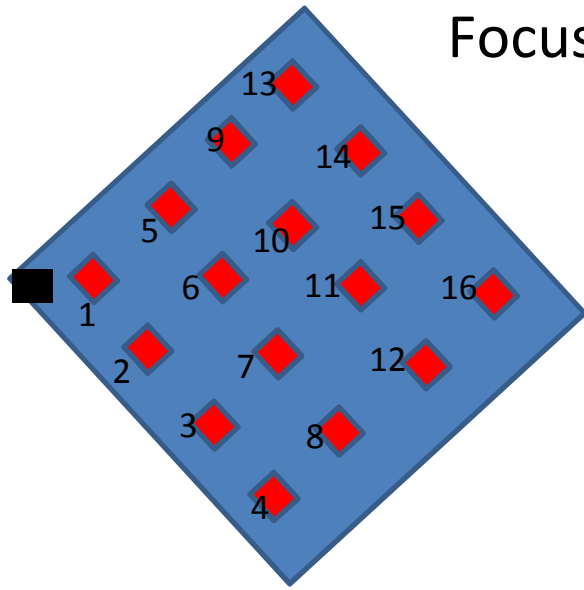


- Variable Energy 10 -100 kV
- Fast Blanking and Chopping
- Liquid Metal Alloy Ion Source
- Mass-Velocity Filter

* Lanthanide series

** Actinide series

Focused Ion Implant Work To-date



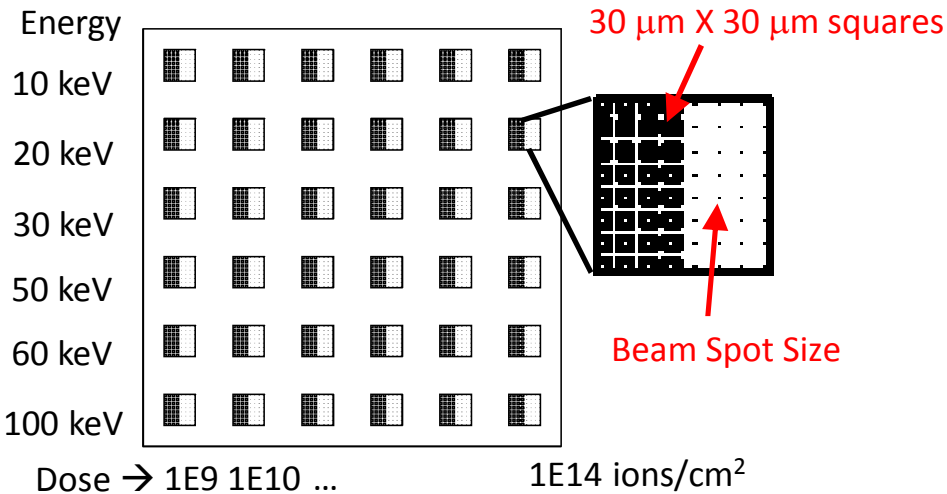
1.) Implanted and annealed a series of samples using:

- 800 keV N for NV creation
- 800 keV Si for SiV creation

Samples provided to E. Waks (UMD) for measurement

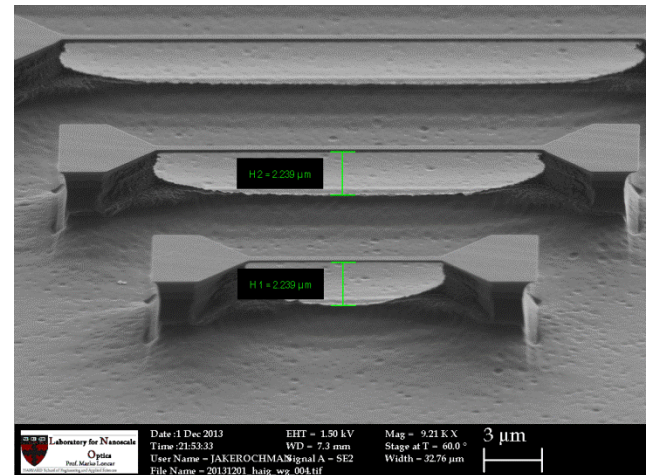
Vary dose over two order of magnitude to explore yield

2.) Si into a sample for D. Englund (MIT)

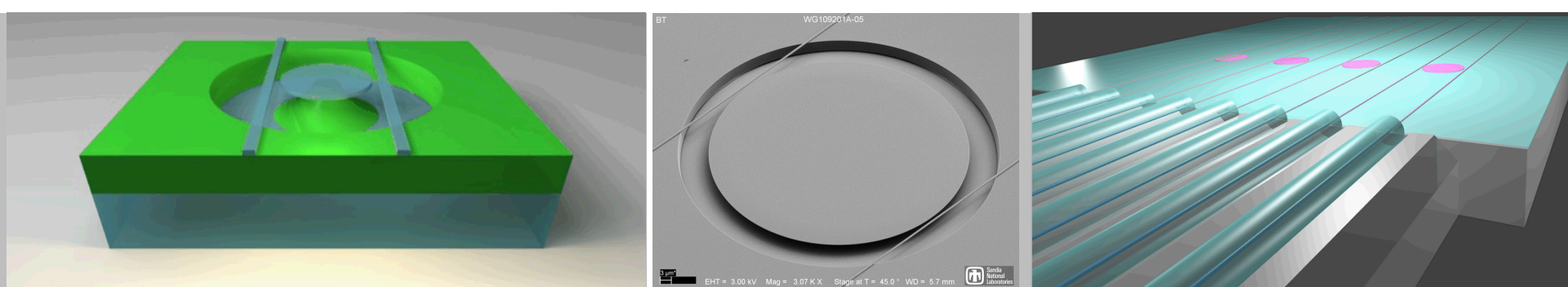


- Yield tester as function energy and dose
Implants underway!

3.) Si into a sample for M. Loncar (Harvard)



We will implant 100 keV Si into the nanowires and hand off to Loncar's group. Samples in route to SNL.



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Milestones

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Ed Bielejec

Sandia Goals for February 2016

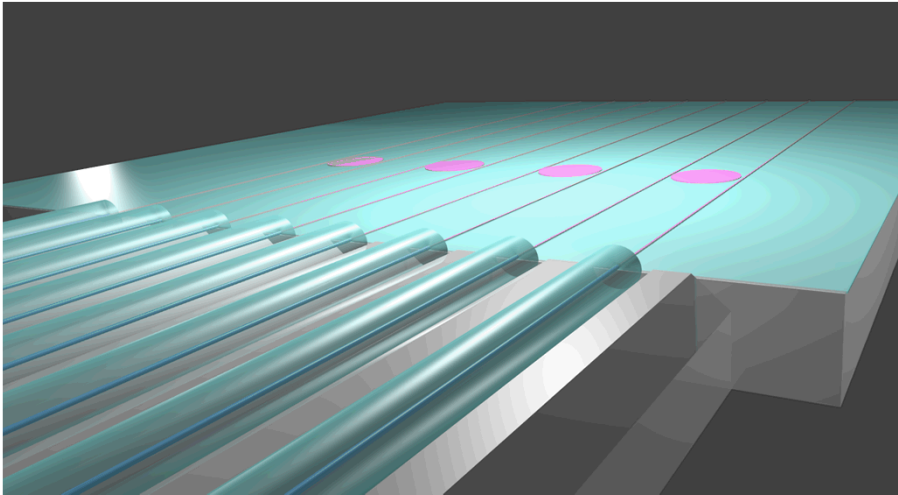
- Improve single device.
- Demonstrate coupling over 8 or 16 channels simultaneously.

- Fabricate and test kinematic bonding model.
- Characterize ease of placing fibers inside of v-grooves.
- Achieve better than 3 dB coupling without a 6-axis alignment.

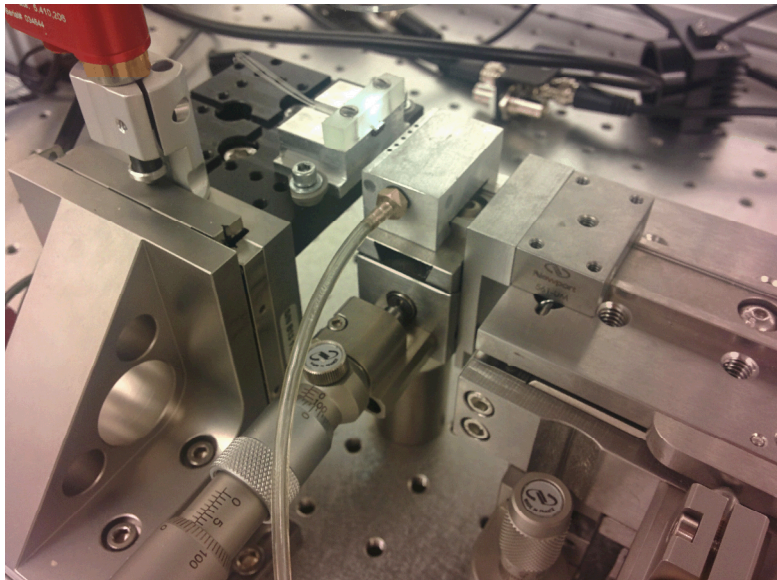
- Characterize ion flux – color center formation relationship.
- In-situ characterization of diamond color center formation.
- Find recipes for deterministic characterization.

- Deliver to UMBC a micro-resonator that is critically coupled and better than 10 dB on-off efficiency.
- Improve reliability of shipping bonded devices.
- Test bonding at low temperatures.

Efficient Fiber-to-chip Coupling



- Improve single device efficiency by 4% per facet to get to -1 dB.
- Demonstrate better than -3 dB over 8 or 16 channels simultaneously (Constrained by fiber tolerances)

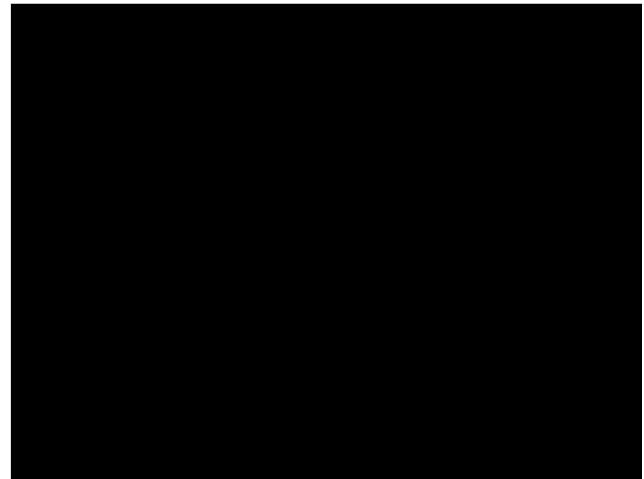
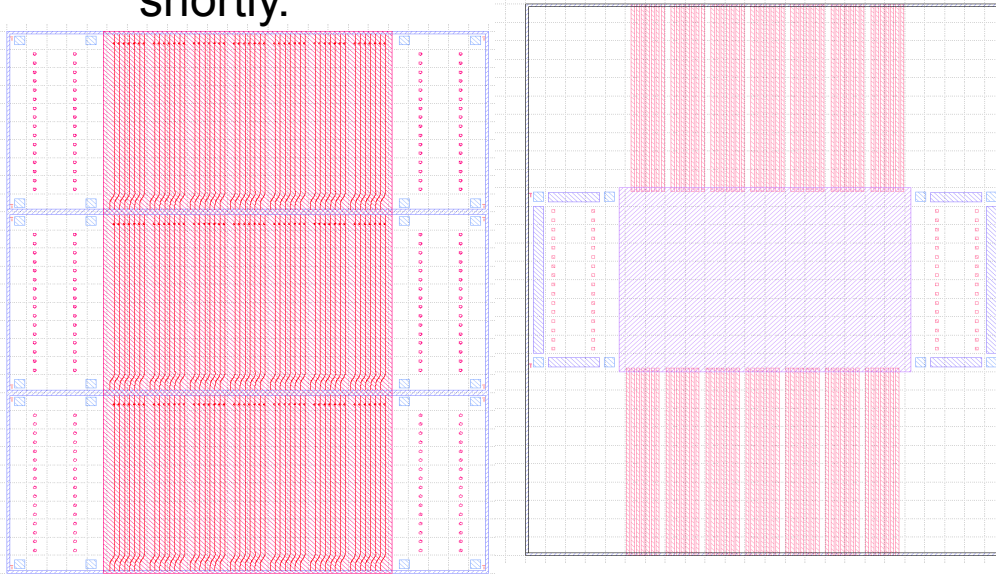


Possible sources of improvement:

- Piezo rotation stages.
- Better chucks for fiber-array and DUT.
- Auto-collimator rotation alignment.

Kinematic Bonding

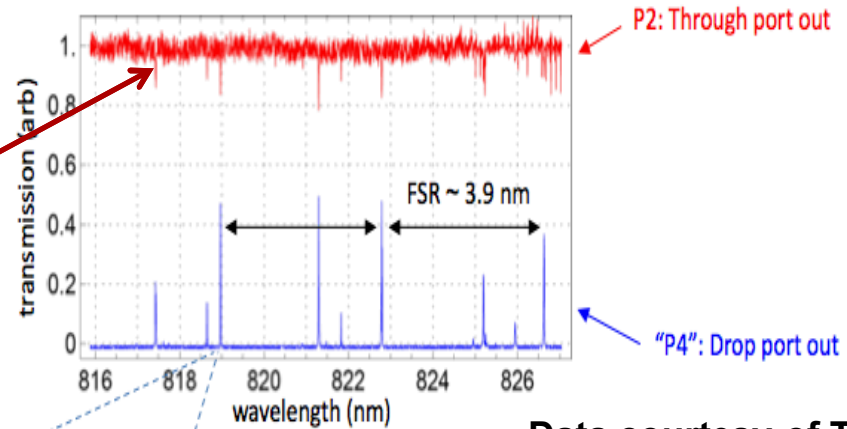
- Mask layout complete – both generic waveguide chip and generic v-groove chip.
- Started lots to determine exact crystallographic orientation for v-groove chip.
- Bonding of chips without optical components underway – will discover FC-150 tolerances shortly.
- V-groove chips start to come out in March 2015.
- Waveguide chips by May 2015.
- Fabrication lots set-to pull and test wafers at every step.
- Flip chip testing by end of May 2015.
- Demonstrate better than 3 dB without active alignment of fiber – may require a second fab iteration.



Deliveries to partners

For UMBC: Already have devices out of fab – should be bonded and delivered by Spring.

- Improve power drop.
- Get better than 10 dB total fiber-to-fiber efficiency.
- Improve Q.
- Vastly improve shipping and bonding reliability by applying epoxy with a micro-syringe.



Data courtesy of T. Pittman

For Northwestern:

- We have not received further instruction.
- In process are thicker micro-rings with anomalous dispersion requested by Yuping Huang.
- New epoxy and bonding techniques can improve delivered devices even more.

Ion Implantation Goals – February 2016

Progress/understanding on two main issues are needed

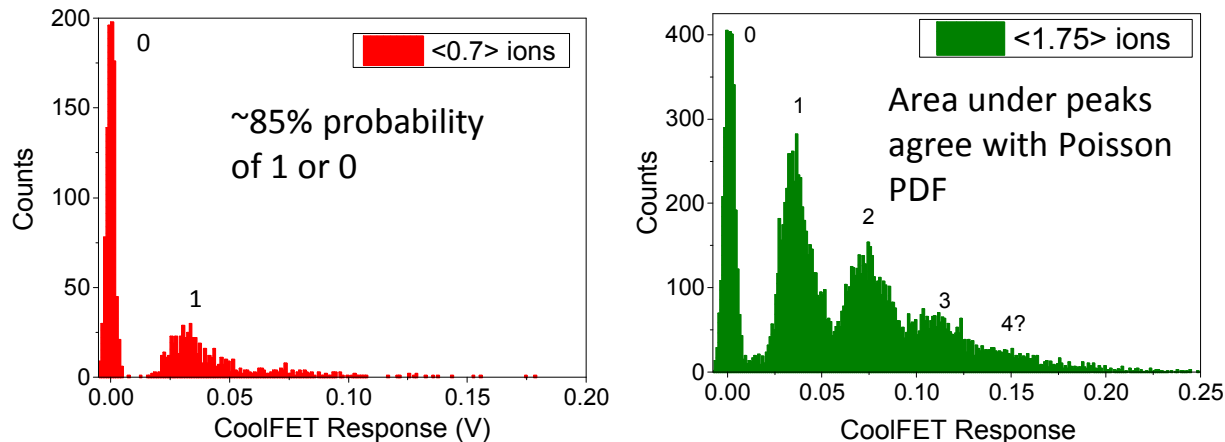
1.) Color Center Formation Yields

- Yield needs to be understood and/or improved as a function of color center type and implantation depth
- Yield can be improved for a given depth with pre-irradiation to damage the localized areas

2.) Deterministic Implants

- Development of on-chip single ion detectors will be needed for single color formation (if yield can be understood/improved)
- Based on our recent success in detecting single low energy heavy ion implants using IBIC in Si we believe this pathway is doable with existing technology.

200 keV Si into Si PIN diode



Diamond IBIC Collect Map

