

Micro-systems for Scalable QKD Components Achievements

*Ryan Camacho

Ian Frank

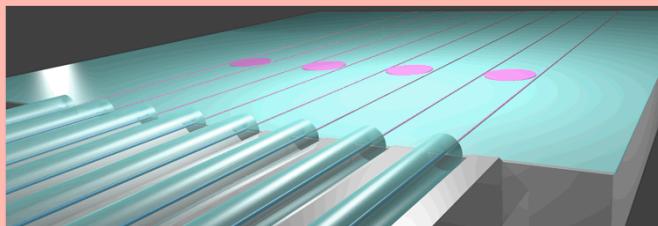
Matthew Tomes

Bruce Burkel

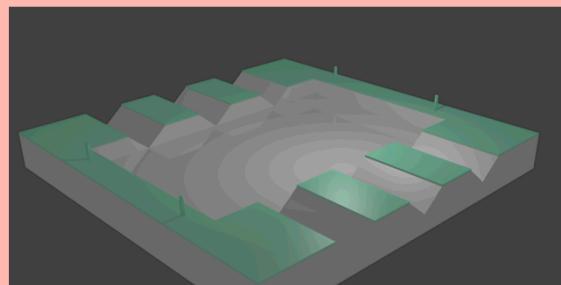
Ed Bielejec

Sandia Efforts

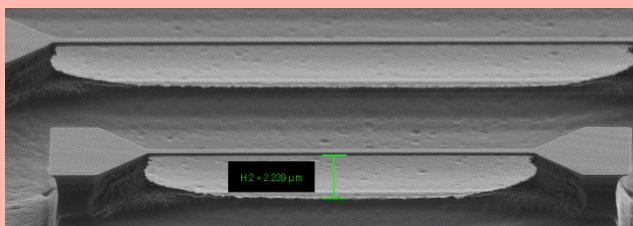
Demonstrate efficient (-1 dB) fiber – to – chip coupling, enabling quantum integration applications.



Develop simplified, scalable kinematic alignment techniques.



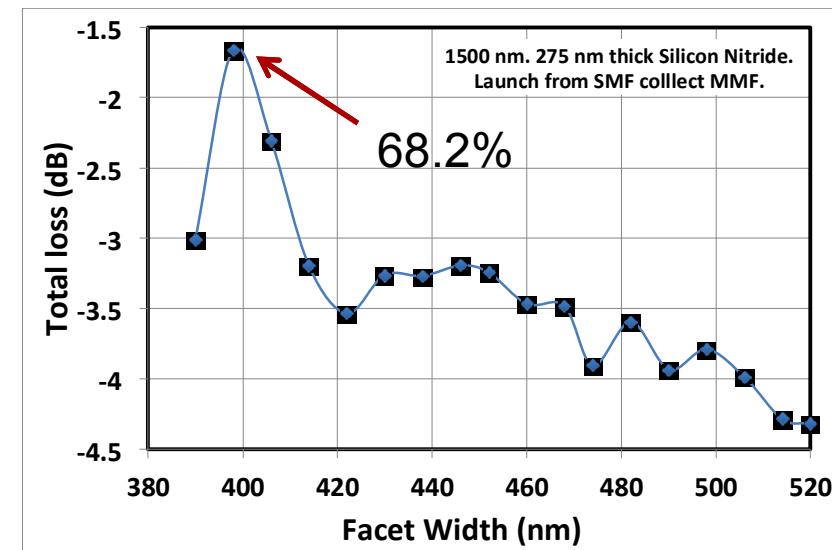
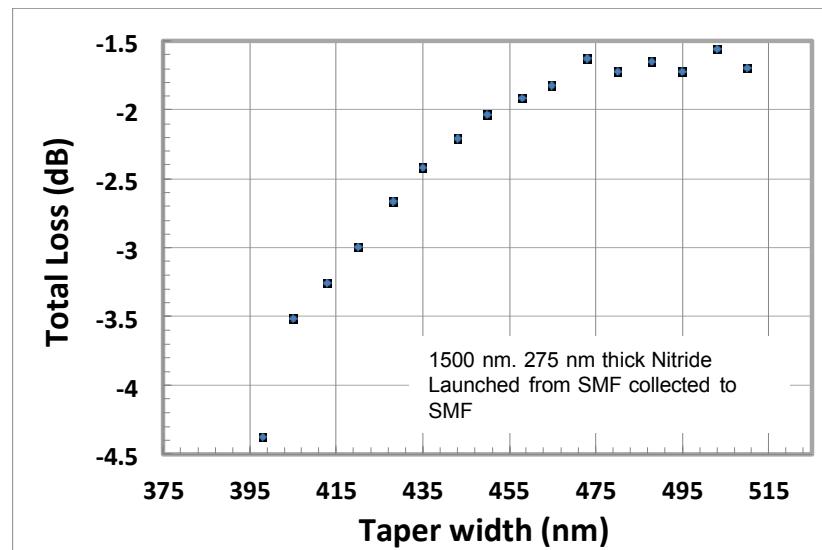
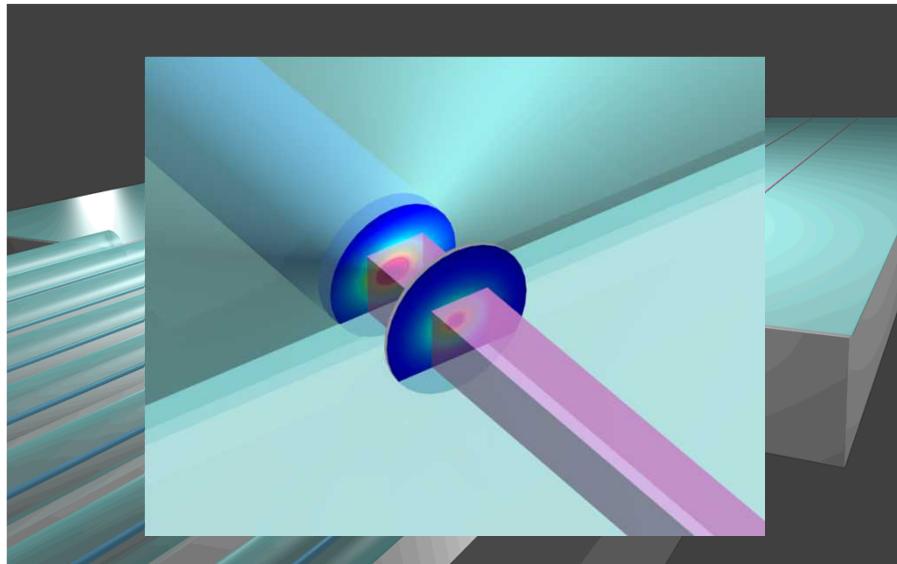
Develop targeted, deterministic ion implantation in diamond substrates.
Supporting: Loncar, Englund, and Waks.



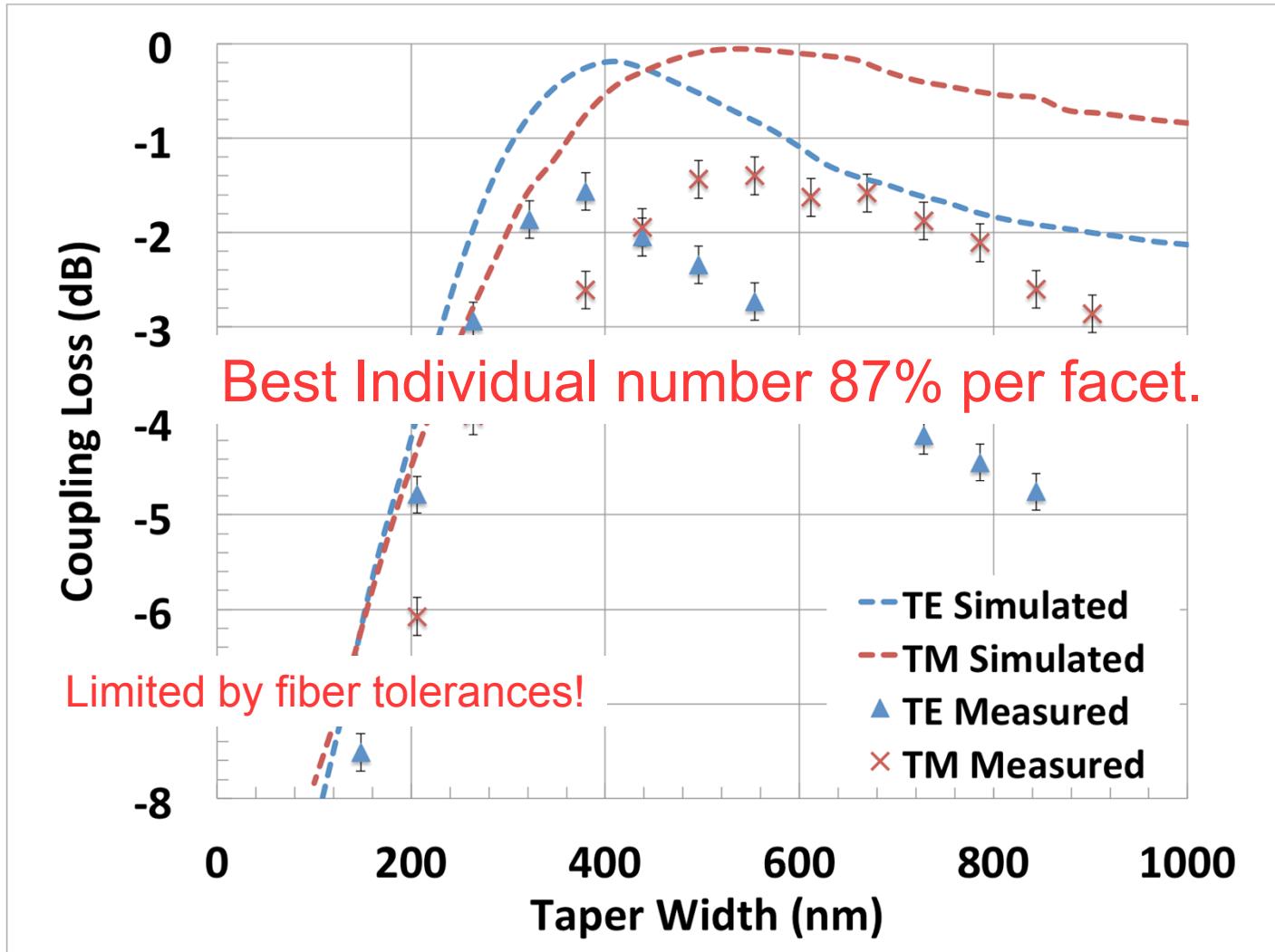
Deliver high quality, packaged, integrated resonators to Northwestern and UMBC teams.



Efficient Fiber-to-chip Coupling

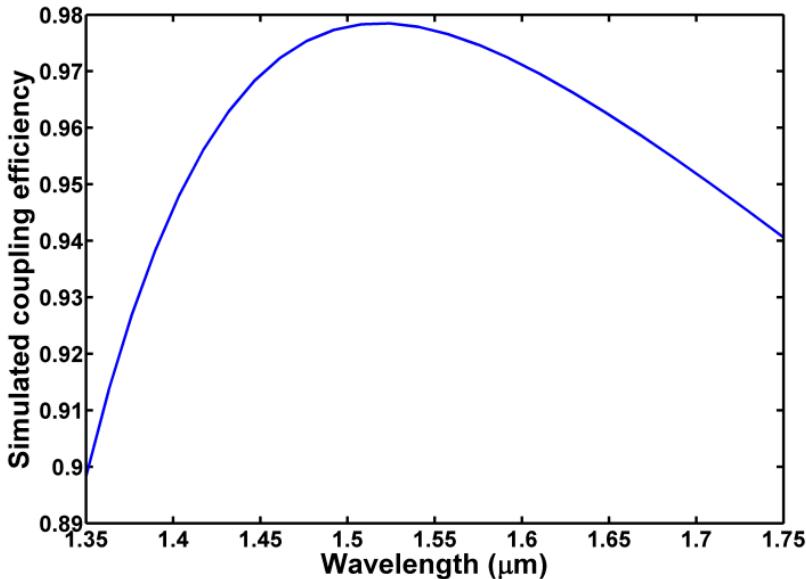


Advances in Fiber-to-chip coupling

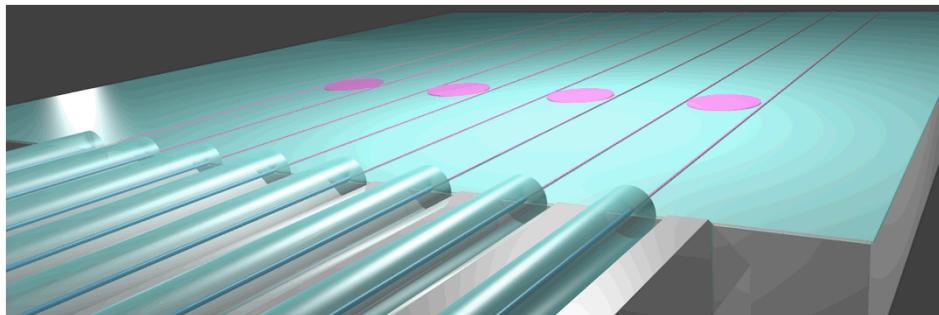


Bandwidth and multiple facets

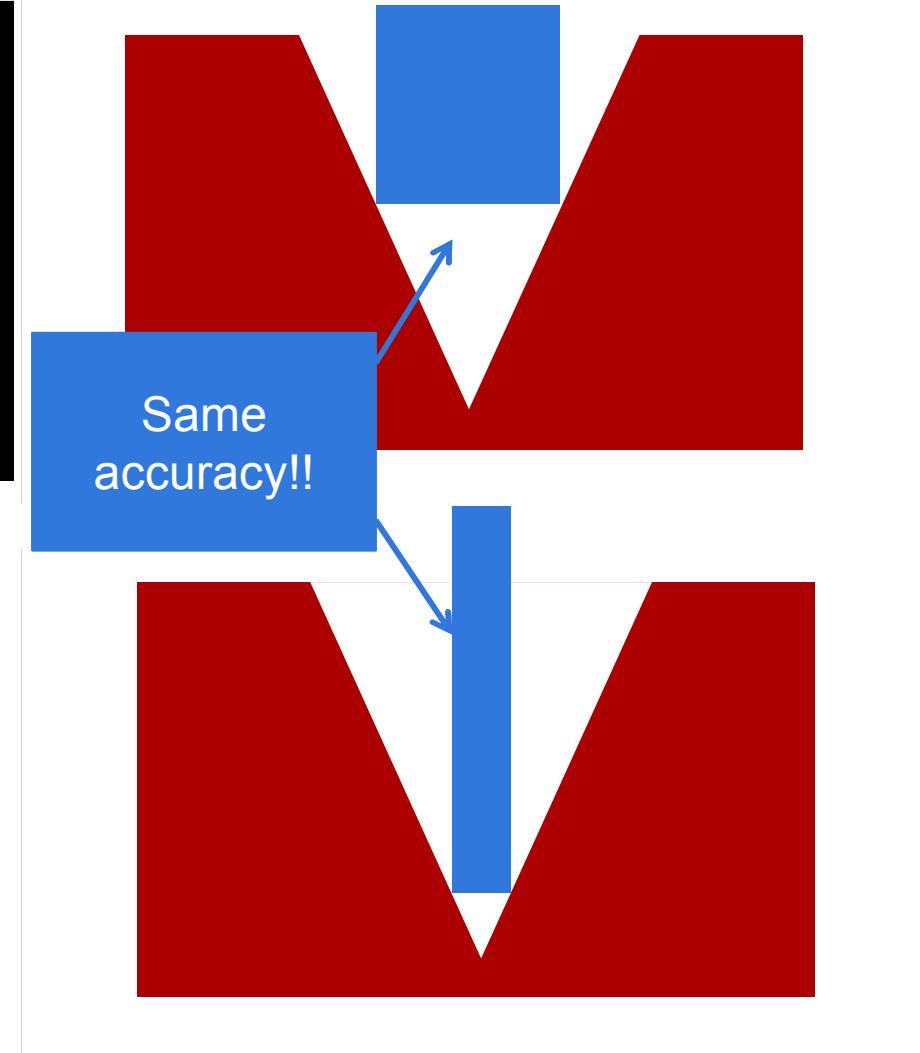
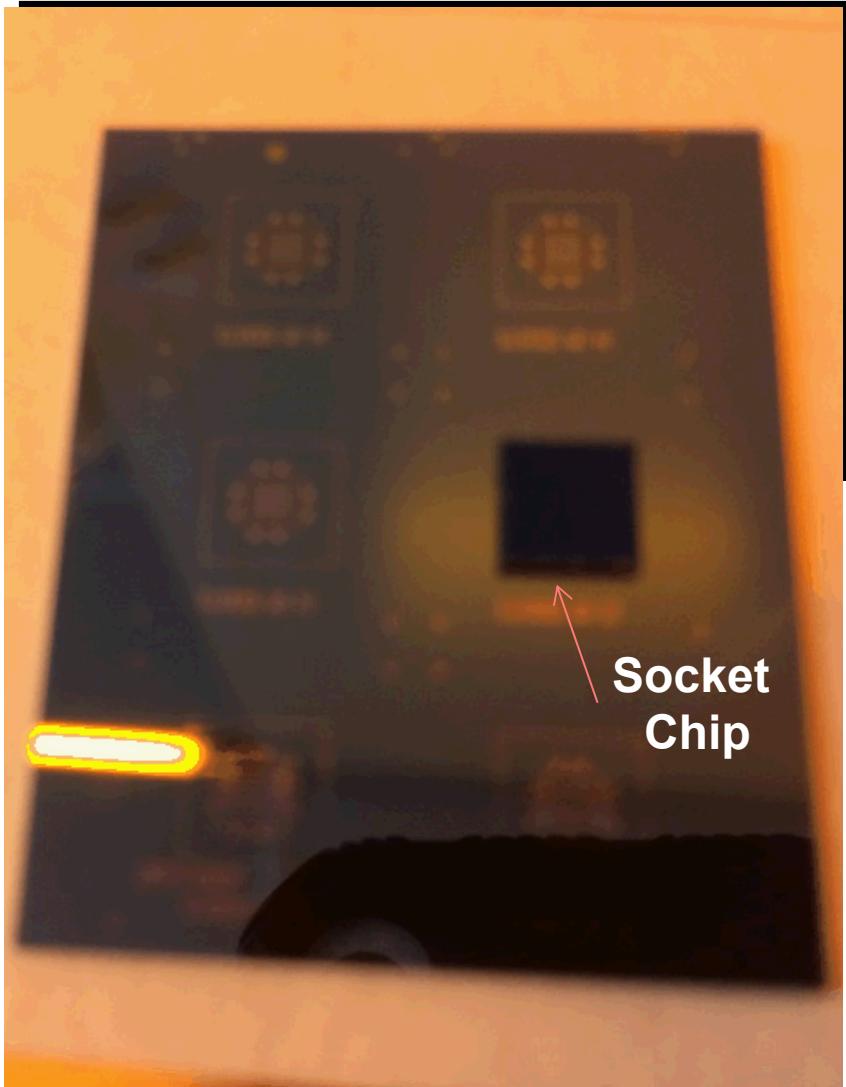
Note: will add experimental data to this.



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

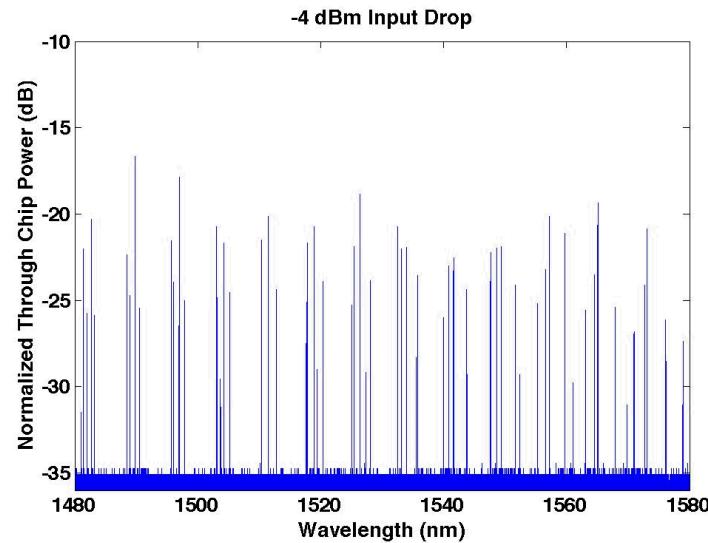
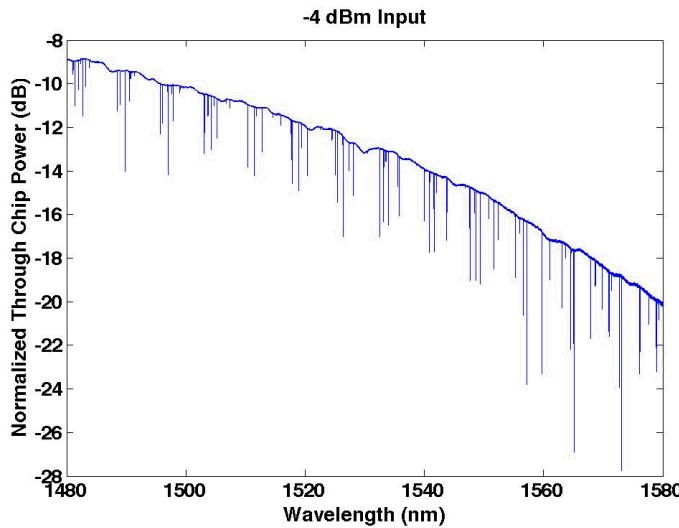


Kinematic Alignment Efforts



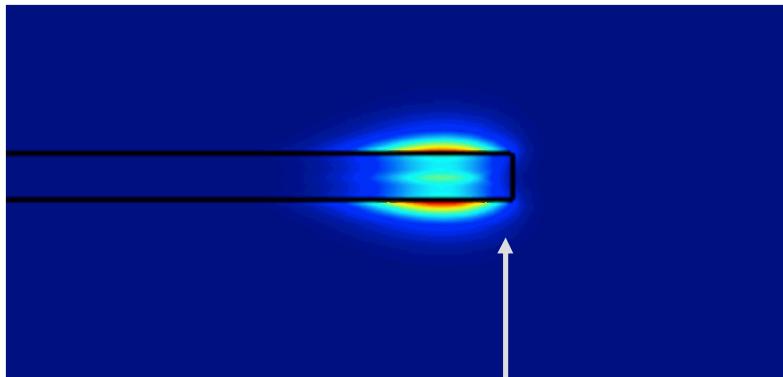
Devices for Northwestern

- 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...

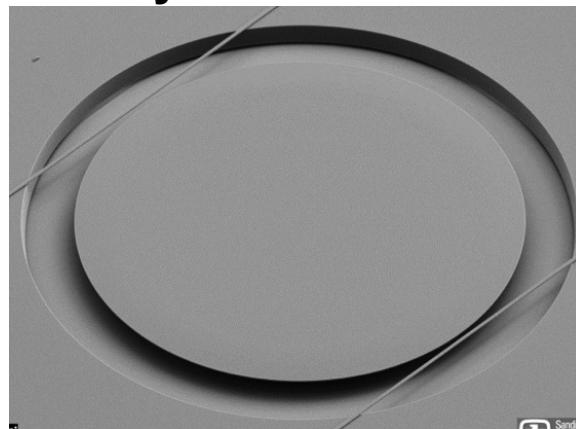


Devices for UMBC

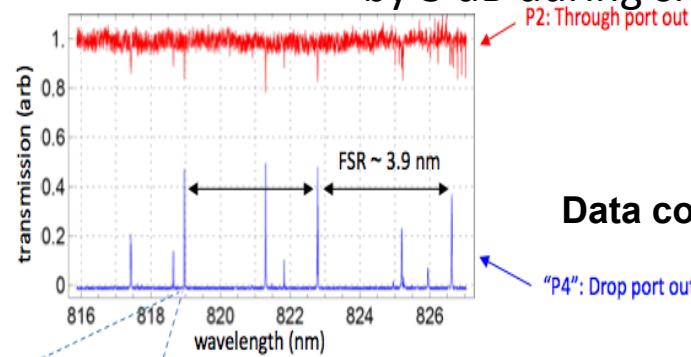
Phase shifting micro-disks



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

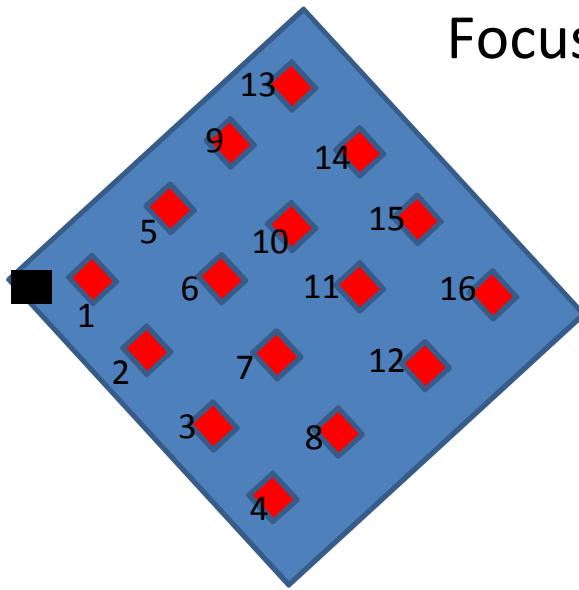
- Four accelerators with focused ion implantation capability
- Range of ion species from H to Bi
- Highlight the *nanolimplanter (nl)*

hydrogen	1	H	1.0079
boron	3	Be	9.0122
lithium	4		
Li	6.941		
sodium	11	magnesium	12
Na	22.990	Mg	24.305
potassium	19	calcium	20
K	39.098	Ca	40.078
rubidium	37	strontium	38
Rb	85.468	Sr	87.62
cesium	55	barium	56
Cs	132.91	Ba	137.33
francium	87	lutefornium	71
Fr	223	hafnium	72
	*	tantalum	73
	*	tungsten	74
	*	rhenium	75
	*	osmium	76
	*	iridium	77
	*	platinum	78
	*	gold	79
	*	mercury	80
	*	thallium	81
	*	lead	82
	*	bismuth	83
	*	poliomium	84
	*	astatine	85
	*	radon	86
	*	rhenium	87
	*	technetium	88
	*	rhodium	89
	*	osmium	90
	*	iridium	91
	*	platinum	92
	*	gold	93
	*	mercury	94
	*	thallium	95
	*	lead	96
	*	bismuth	97
	*	poliomium	98
	*	astatine	99
	*	radon	100
	*	rhenium	101
	*	technetium	102
	*	ytterbium	103

Green – demonstrated at other labs
Purple – demonstrated at SNL
Yellow – attempting at SNL

boron	5	carbon	6	nitrogen	7	oxygen	8	fluorine	9	helium	2
B	10.811	C	12.011	N	14.007	O	15.999	F	18.998	neon	10
aluminum	13	silicon	14	phosphorus	15	sulfur	16	chlorine	17	argon	18
Al	26.982	Si	28.095	P	30.974	S	32.065	Cl	35.453	Ar	39.948
gallium	31	germanium	32	arsenic	33	antimony	34	bromine	35	krypton	36
Ga	69.720	Ge	72.610	As	74.922	In	78.95	Br	83.80	Xe	131.29
cadmium	48	indium	49	tin	50	tin	51	iodine	53		
Cd	112.41	In	114.93	Sn	118.21	Sb	121.76	Te	126.90		
tin	52	antimony	51	lead	82	Bi	127.60	At	131.29		
thallium	81	thallium	81	thallium	82	thallium	83	radon	86		
lead	82	lead	82	lead	82	lead	83	radon	86		
polonium	84	polonium	84	polonium	84	polonium	85	radon	86		
astatine	85	astatine	85	astatine	85	astatine	86	radon	86		
radon	86	radon	86	radon	86	radon	87	radon	86		
rhenium	87	rhenium	87	rhenium	87	rhenium	88	radon	86		
technetium	88	technetium	88	technetium	88	technetium	89	radon	86		
lutefornium	71	hafnium	72	hafnium	72	hafnium	73	radon	86		
hafnium	72	tantalum	73	tantalum	73	tantalum	74	radon	86		
tantalum	73	tungsten	74	tungsten	74	tungsten	75	radon	86		
tungsten	74	rhenium	75	rhenium	75	rhenium	76	radon	86		
rhenium	75	osmium	76	osmium	76	osmium	77	radon	86		
osmium	76	iridium	77	iridium	77	iridium	78	radon	86		
iridium	77	platinum	78	platinum	78	platinum	79	radon	86		
platinum	78	gold	79	gold	79	gold	80	radon	86		
gold	79	mercury	80	mercury	80	mercury	81	radon	86		
mercury	80	thallium	81	thallium	81	thallium	82	radon	86		
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lead	82	bismuth	83	bismuth	83	bismuth	84	radon	86		
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radon	172	radon	172</								

Focused Ion Implant Work To-date



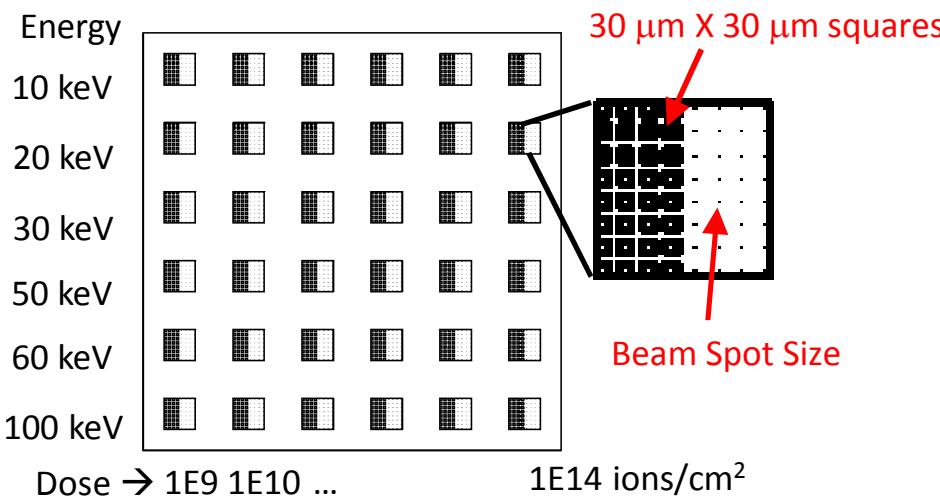
1.) Implanted and annealed a series of samples using:

- 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

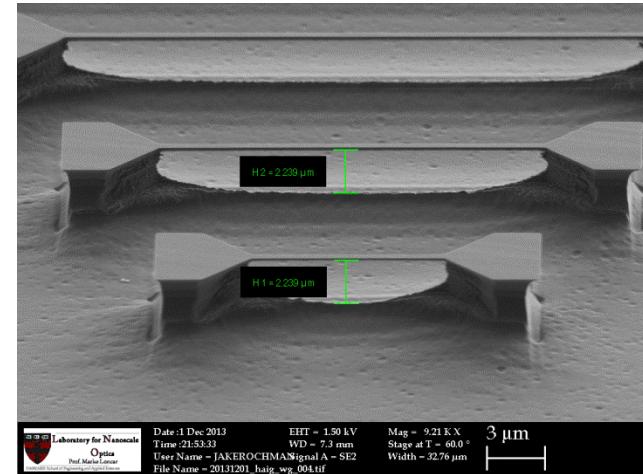
2.) Si into a sample for D. Englund (MIT)



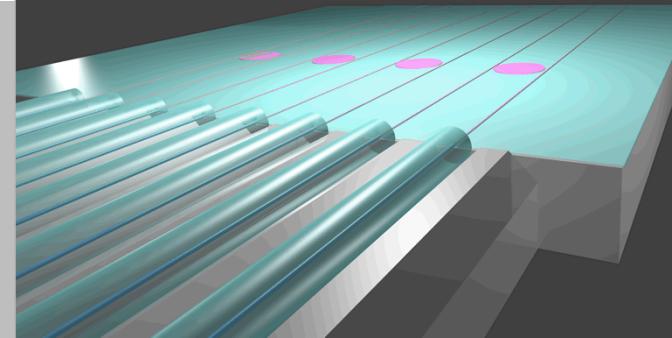
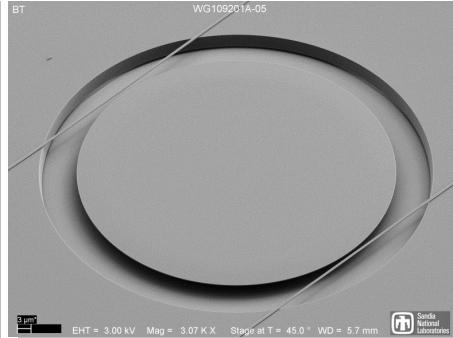
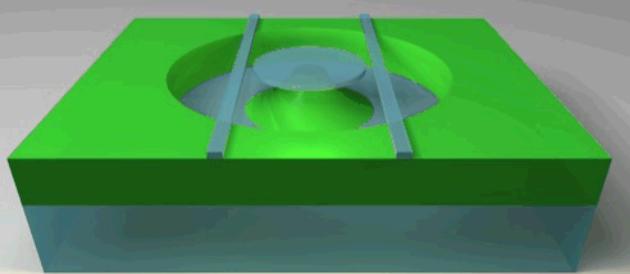
- Yield tester as function energy and dose

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.



Micro-systems for Scalable QKD Components

Milestones
*Ryan Camacho

Ian Frank

Matthew Tomes

Bruce Burkel

Ed Bielejec

Sandia Goals for February 2016



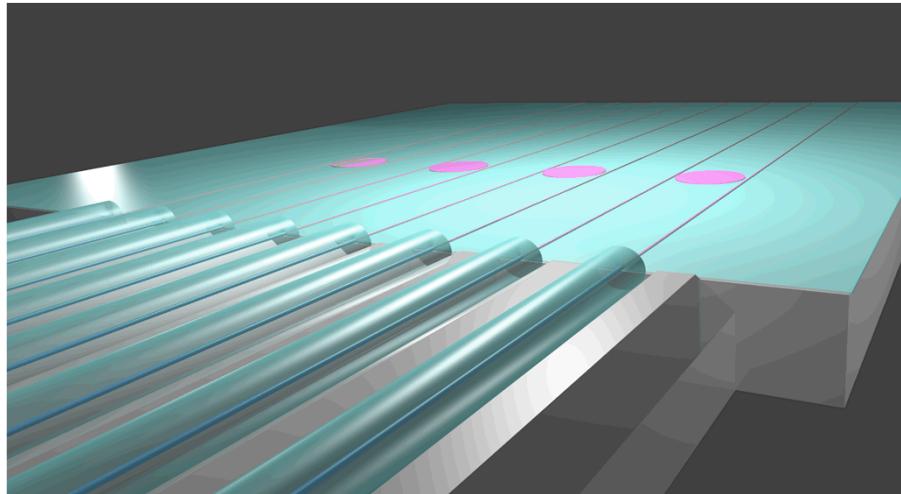
- Improve single device.
- Demonstrate coupling over 8 or 16 channels simultaneously.

- 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.

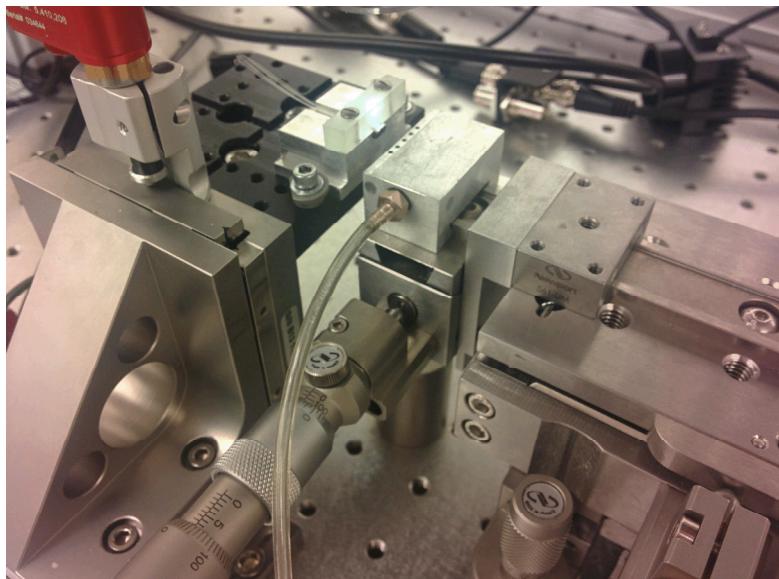
- Characterize ion flux – color center formation relationship.
- In-situ characterization of diamond color center formation.
- Find recipes for deterministic characterization.

- 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)

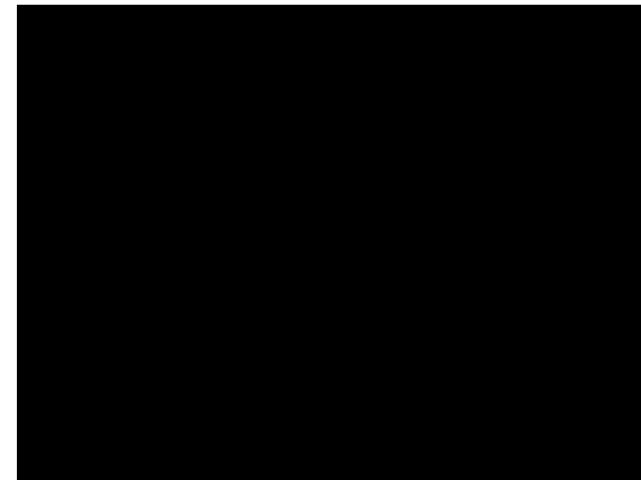
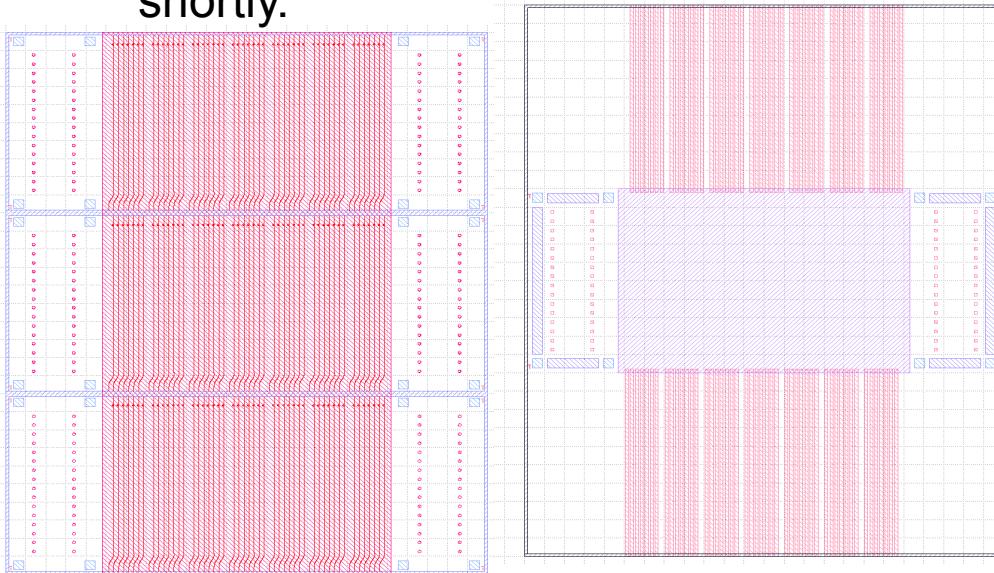


Possible sources of improvement:

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

Kinematic Bonding

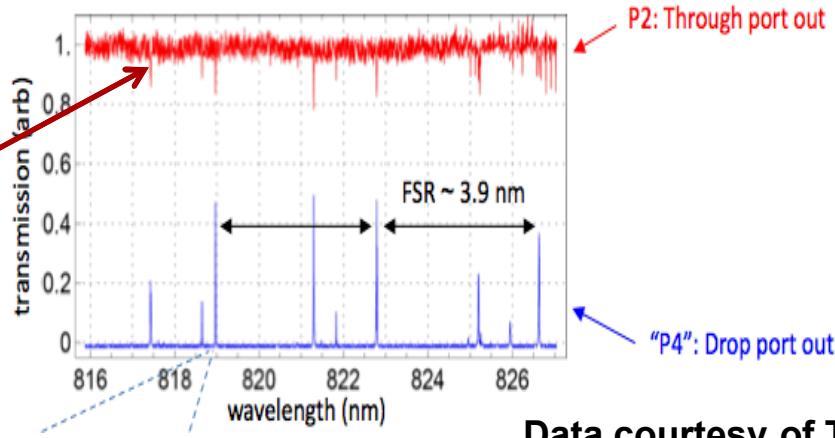
- Mask layout complete – both generic waveguide chip and generic v-groove chip.
- Started lots to determine exact crystallographic orientation for v-groove chip.
- Bonding of chips without optical components underway – will discover FC-150 tolerances shortly.
- V-groove chips start to come out in March 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.

