Thin Diamond Time-of-Flight Detectors

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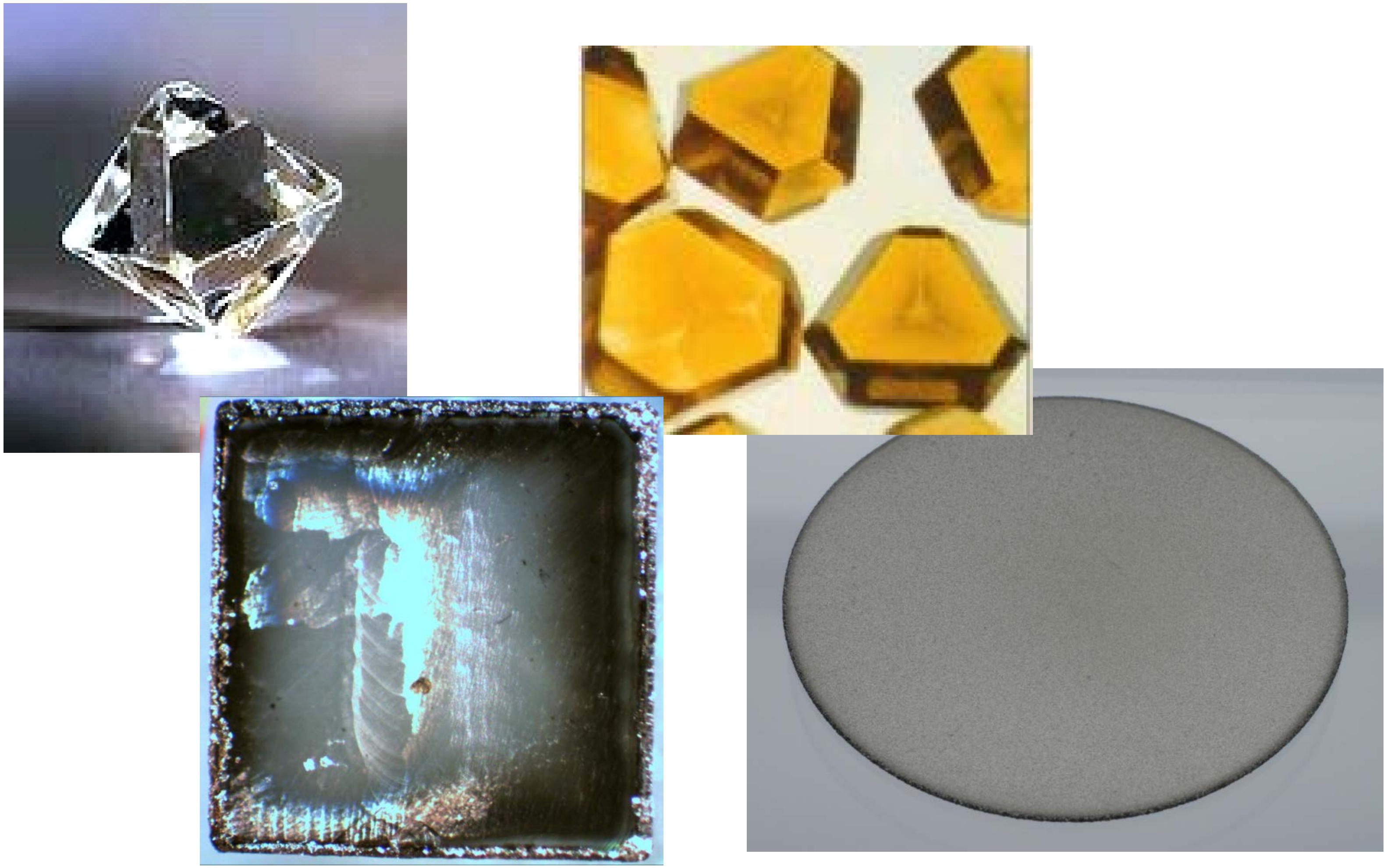
Applied Diamond, Inc

DOE NP SBIR/STTR Exchange Meeting
August 6 & 7, 2015

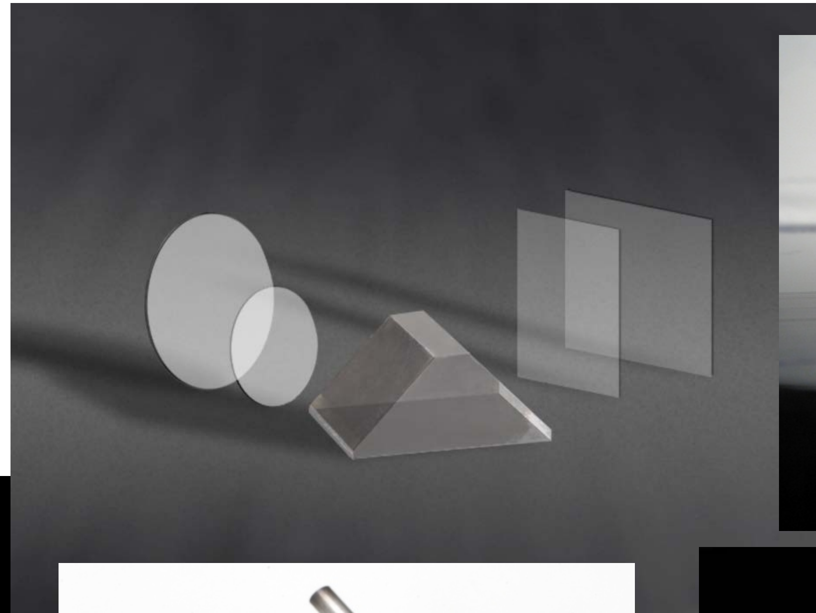
Outline

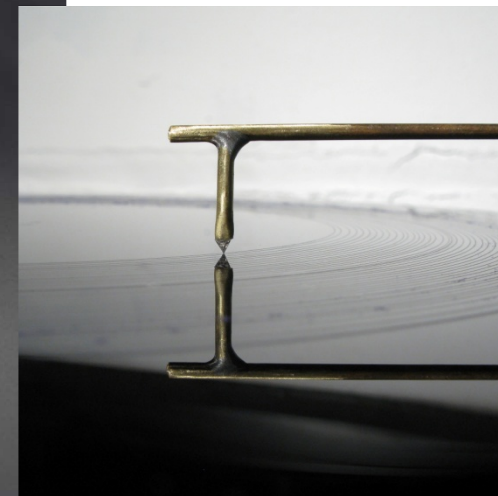
- A bit about Applied Diamond
- Topic and Challenges
- Progress to-date
  - Diamond Growth
  - Material Removal
  - TOF Testing
  - Characterization
  - Packaging
- Commercialization

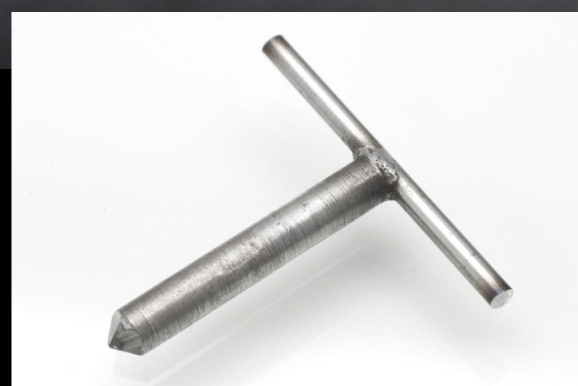
Diamond – Types and Sources



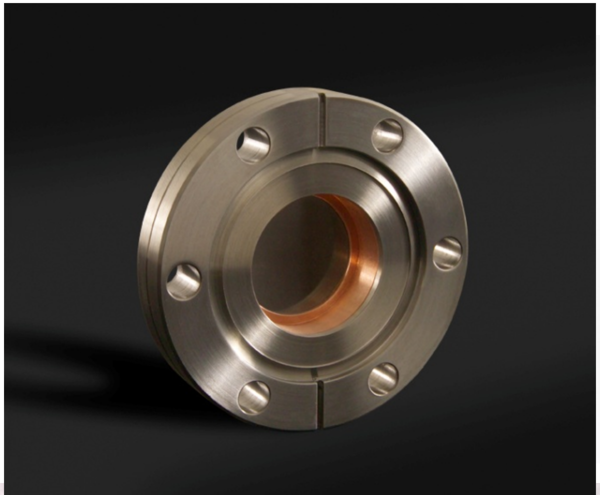
Diamond – Finished Products (single crystal)

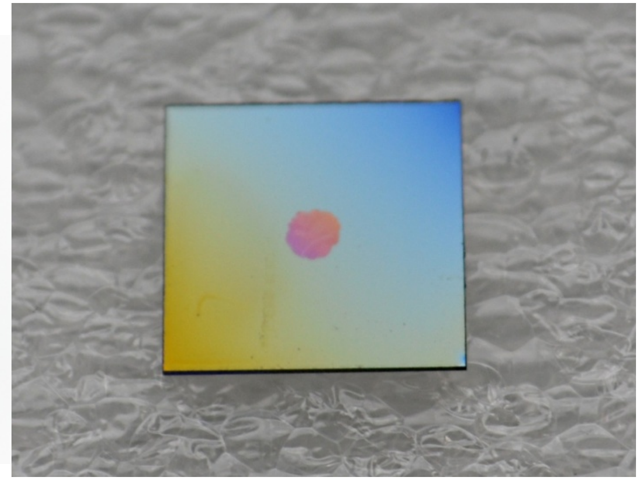


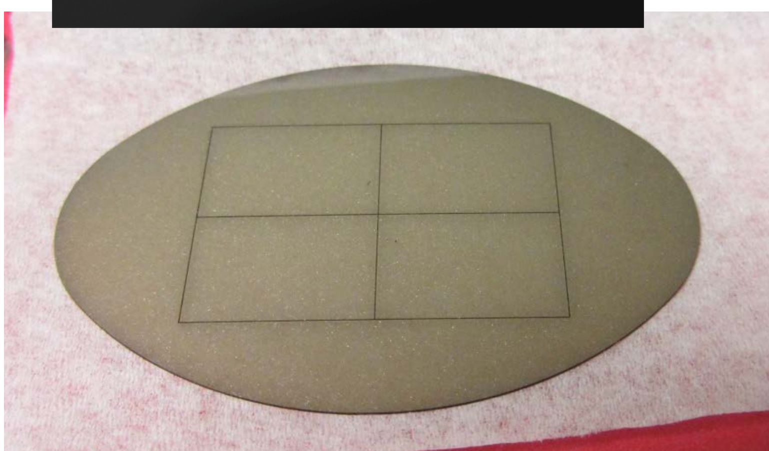


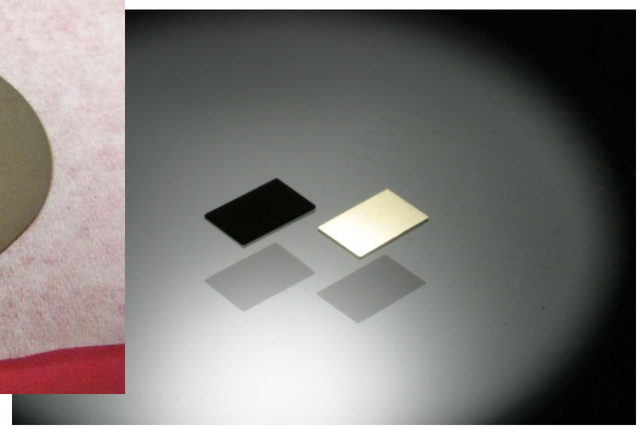


Diamond – Finished Products (polycrystalline)









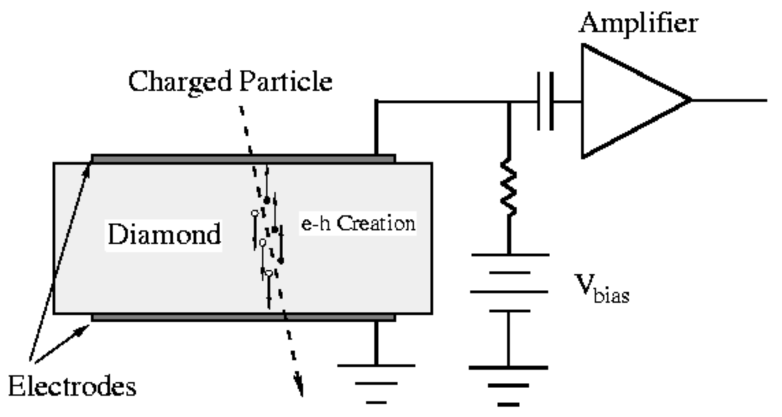
Solicitation Topic and Challenges

Future rare isotope beam facilities like FRIB will provide beams with unprecedented intensity, creating a challenge for single particle tracking and beam profile measurements. The development of position sensitive fast particle detectors for particle tracking/timing and with high rate capability would be desirable. Ideally these detectors would provide both position and timing measurements in a transmission mode and be radiation resistant and of very homogenous density and thickness.

Time-of-Flight Detectors – square cm, segmented
Focal Plane Array Detector – 20 cm x 2 cm, segmented

Uniform quality providing adequate S/N
Uniform mass (thickness and density)
Transmission mode = as thin as possible

Why Diamond?



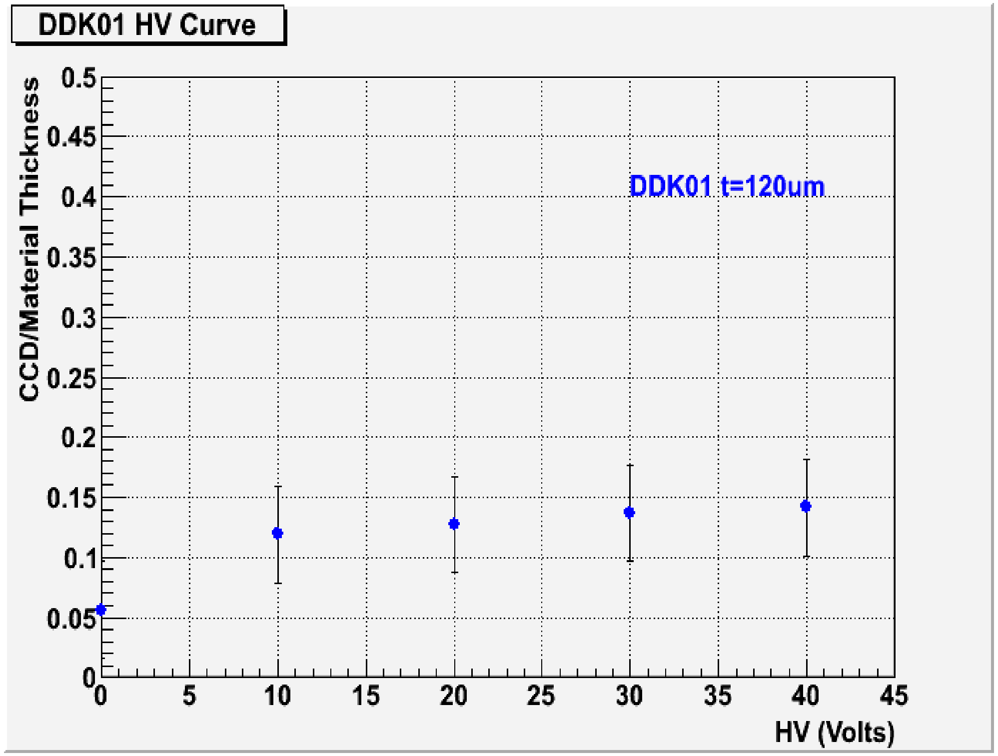
<u>Solid-State Ionization Chamber</u>

- 36 e-h pairs created per um of diamond traversed per MIP
- Charges drift responding to bias voltage creating measured signal
- Trapped by defects in material so charge collection distance is average distance an e-h pair drift apart

- Radiation hardness tested and found superior with wide range of particles/conditions.
- Smaller dielectric constant provides lower capacitance and lower noise.
- Very high thermal conductivity so managing thermal load is easier.

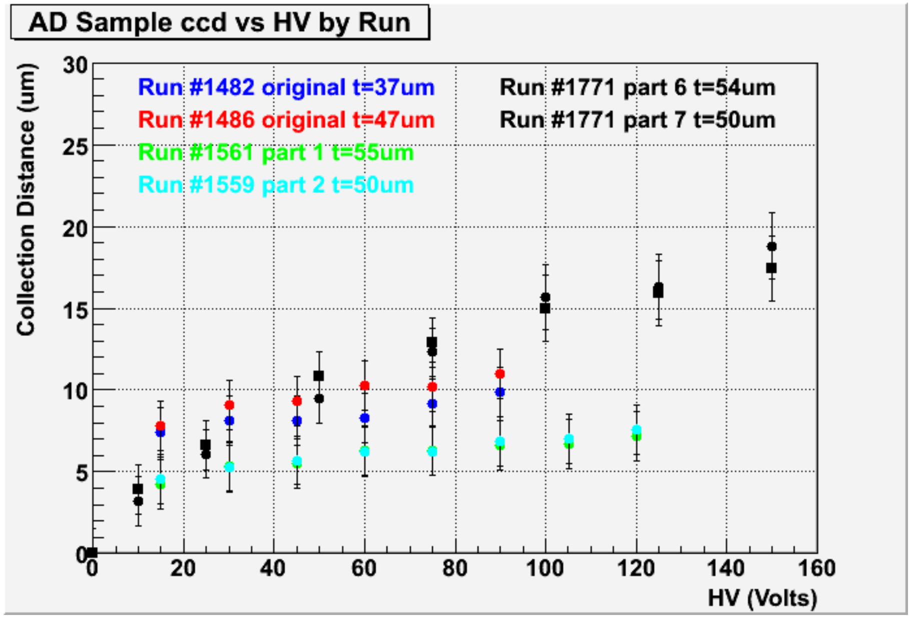
Diamond Growth Progress

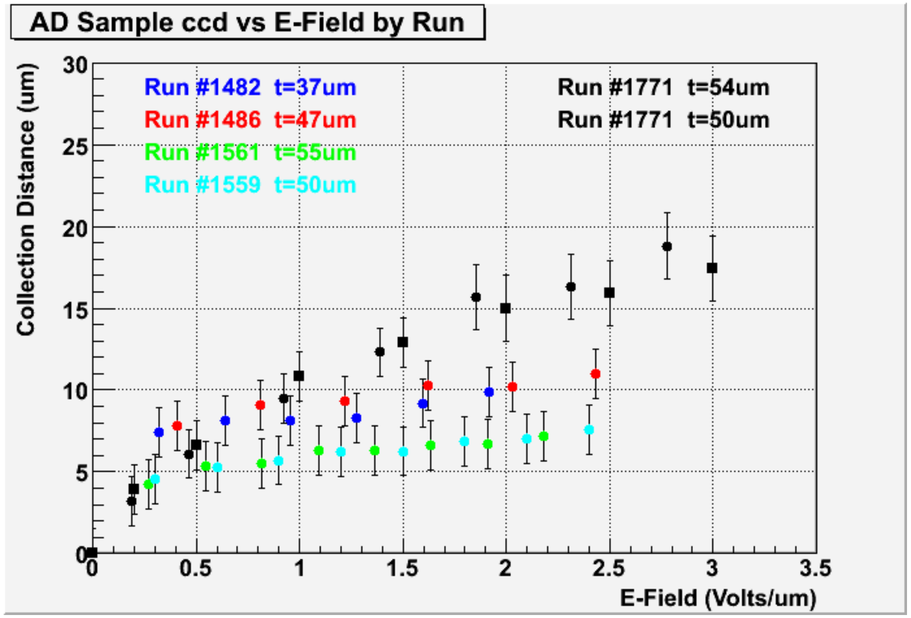
Early results on 100μm+ films



Diamond Growth Progress

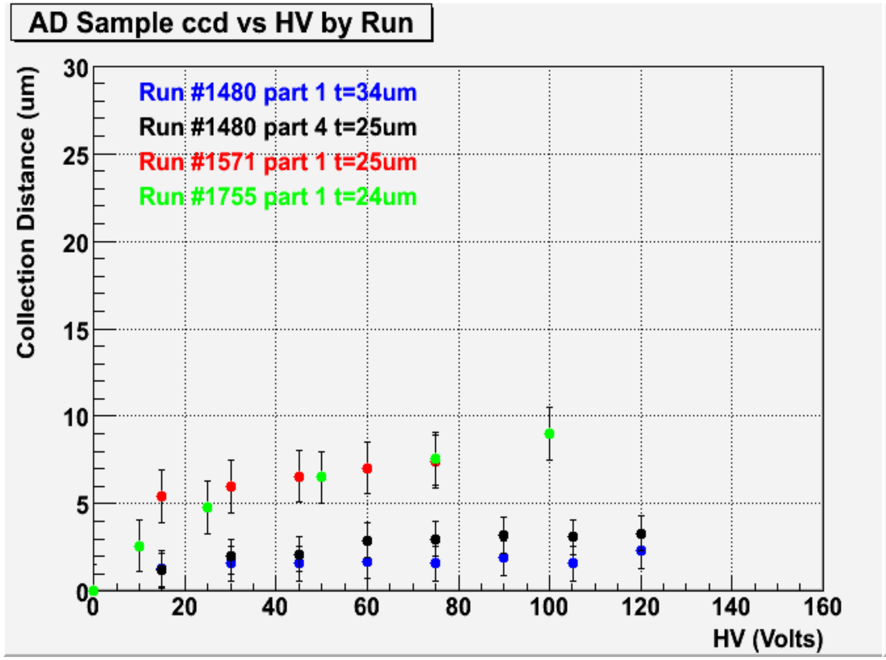
Early vs. current results on 50 – 60 μm films

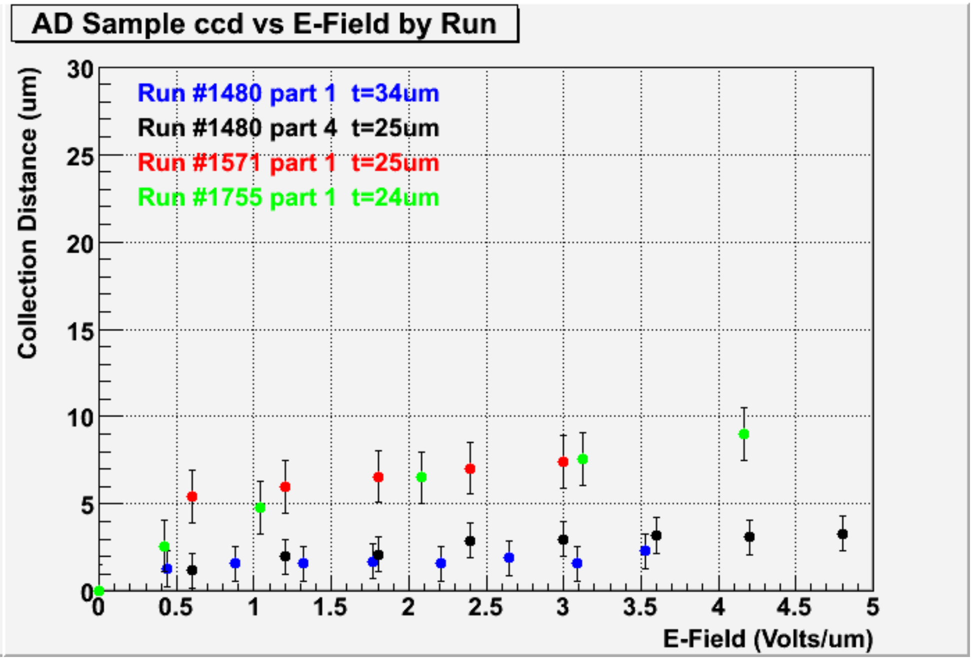




Diamond Growth Progress

Early vs. current results on 25 – 30 μm films





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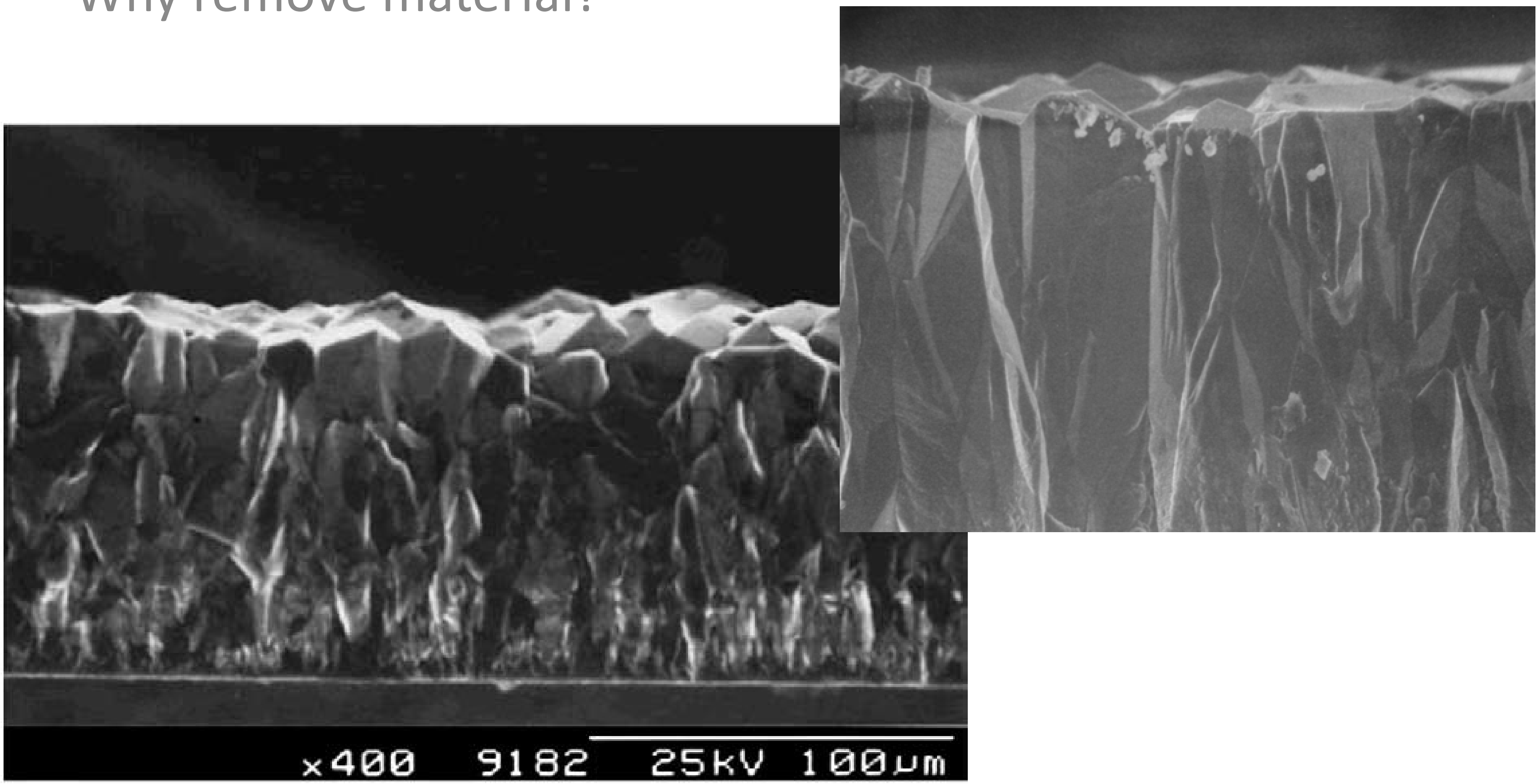
Material Removal Progress

Why remove material?



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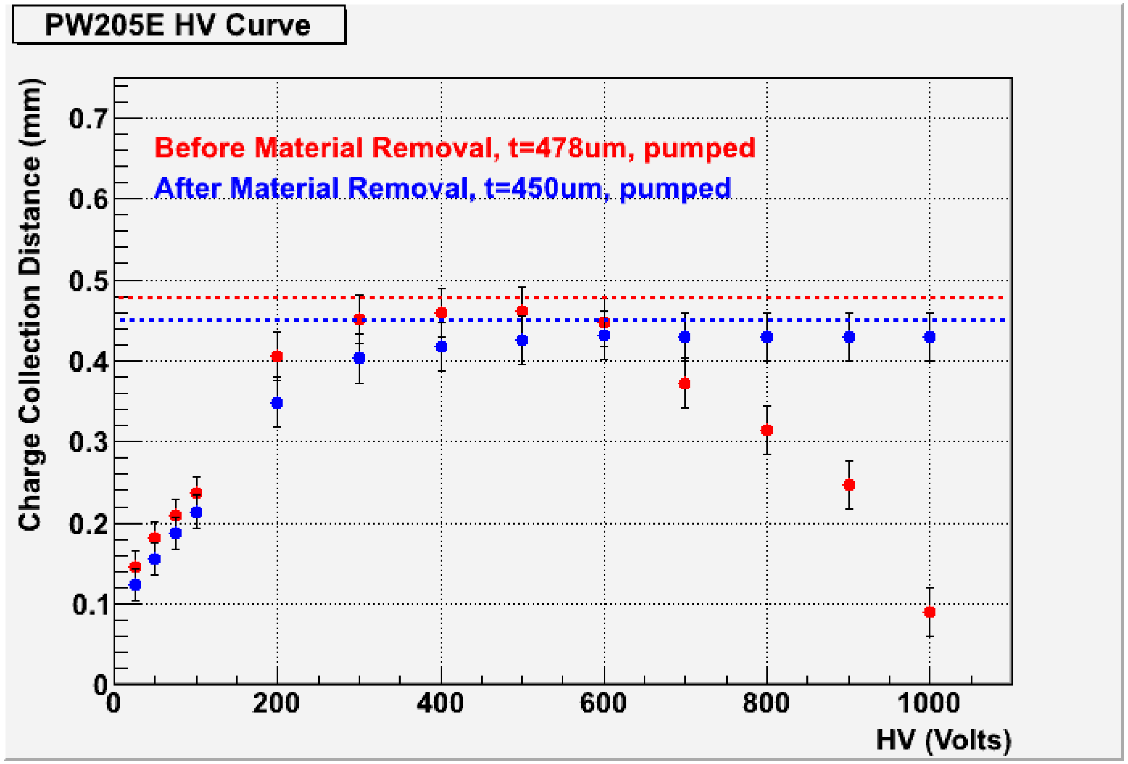
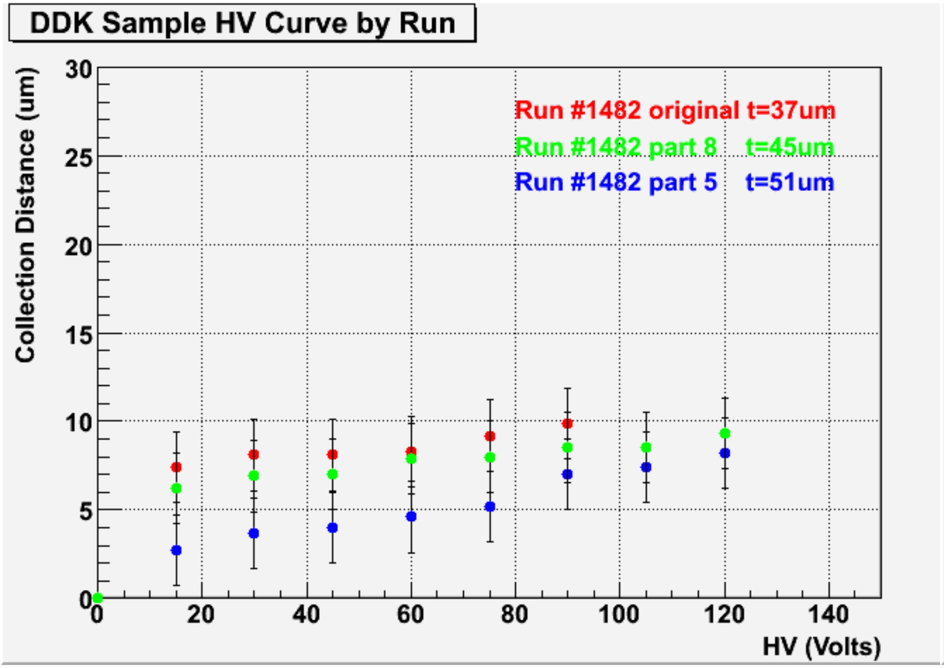
Material Removal Progress

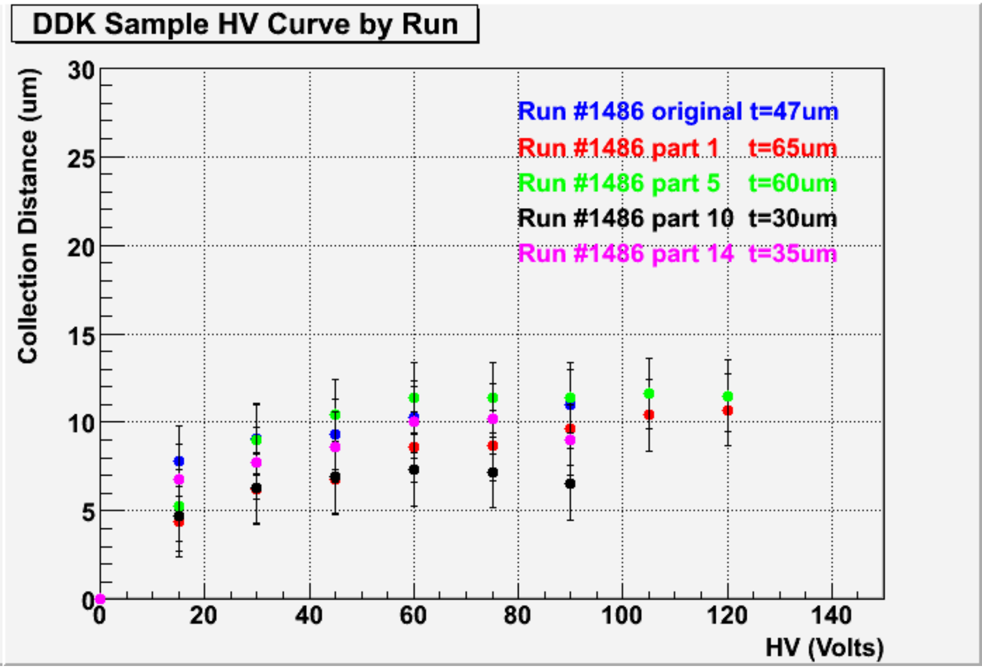
Early results - scCVD



Material Removal Progress

Various methods on polyCVD – cont.



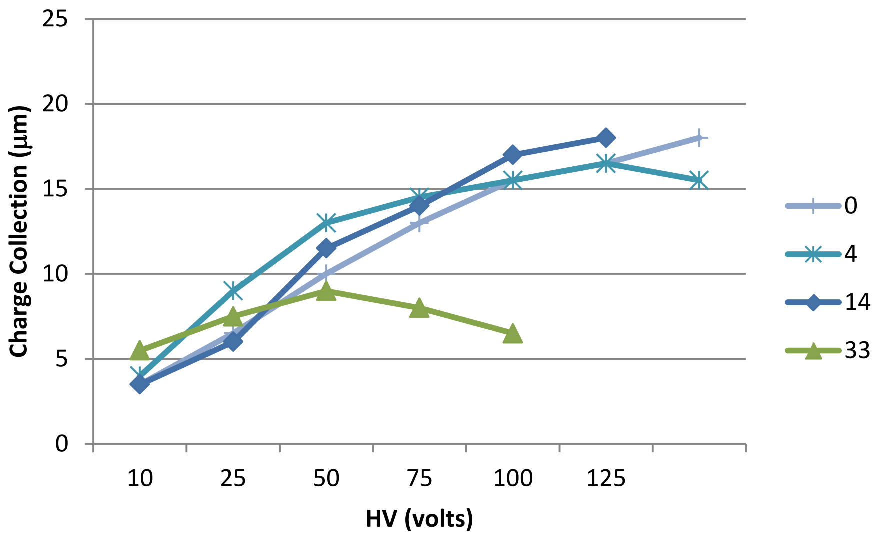


Material Removal Progress

Thickness control by subtraction

Fine control of thickness …

… without affecting performance



Material Removal Progress

Effect of back-etching on CCD

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Time-of-Flight Results

^{232}U alpha particles with energy of 5.3MeV.

Bias = 100V

Leakage < 1 nA

Rise time ~ 0.8 ns

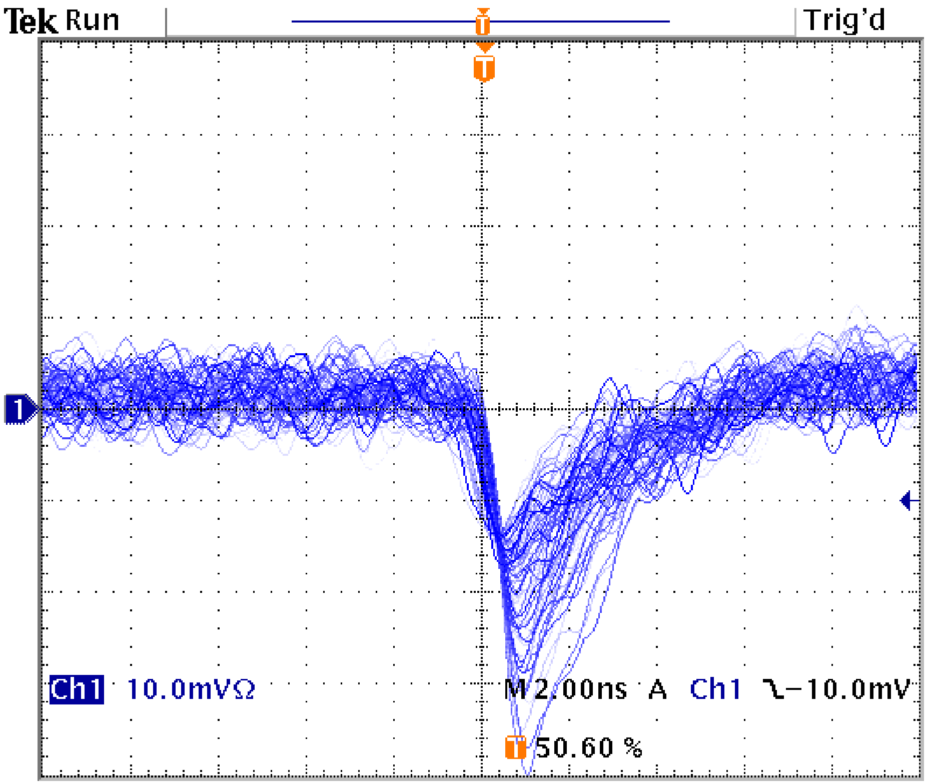
Decay/rise time ~ 3:1

S/N ~ 5

With 100 MeV/u particles, energy loss of:

11.4 MeV with ^{20}Ne

798 MeV with ^{238}U



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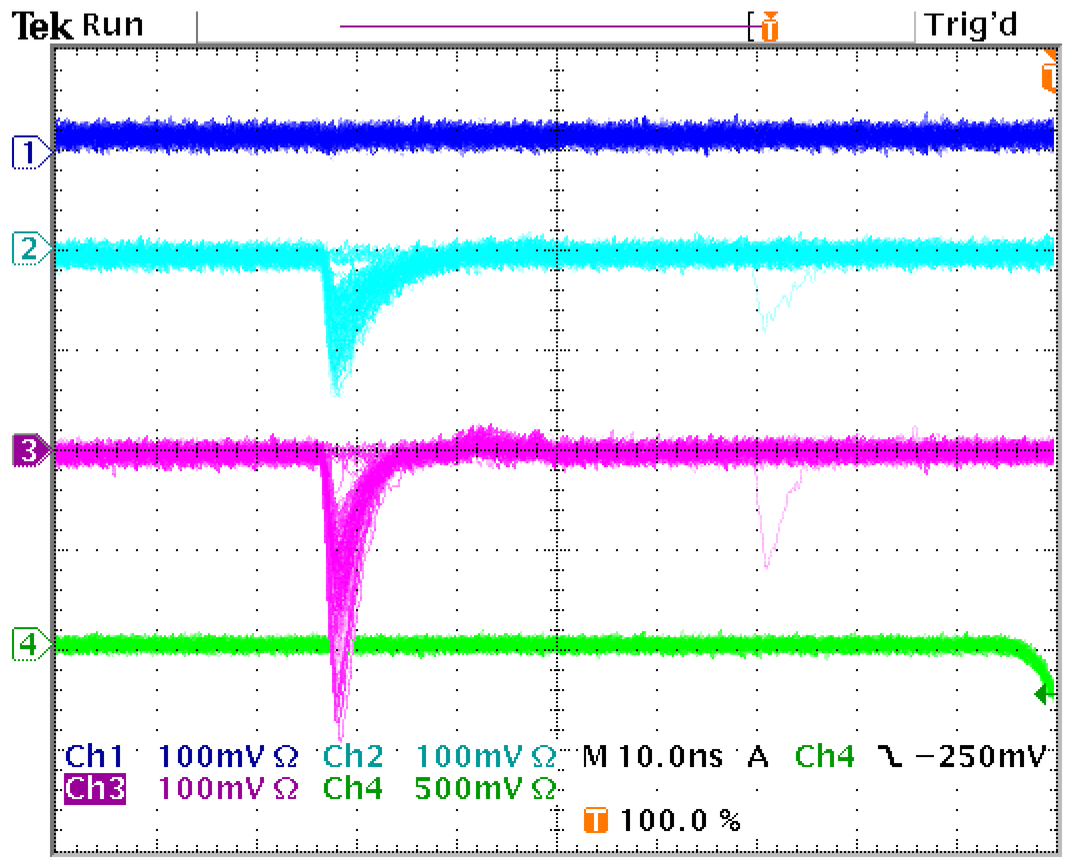
Time-of-Flight Results

^{40}Ca beam with energy of 140MeV/u.

1 – 65 μm thick
2 – 60 μm thick
3 – 50 μm thick

Sample 3:
E_{loss} = 36 MeV
trigger eff = 81% @ 100V bias



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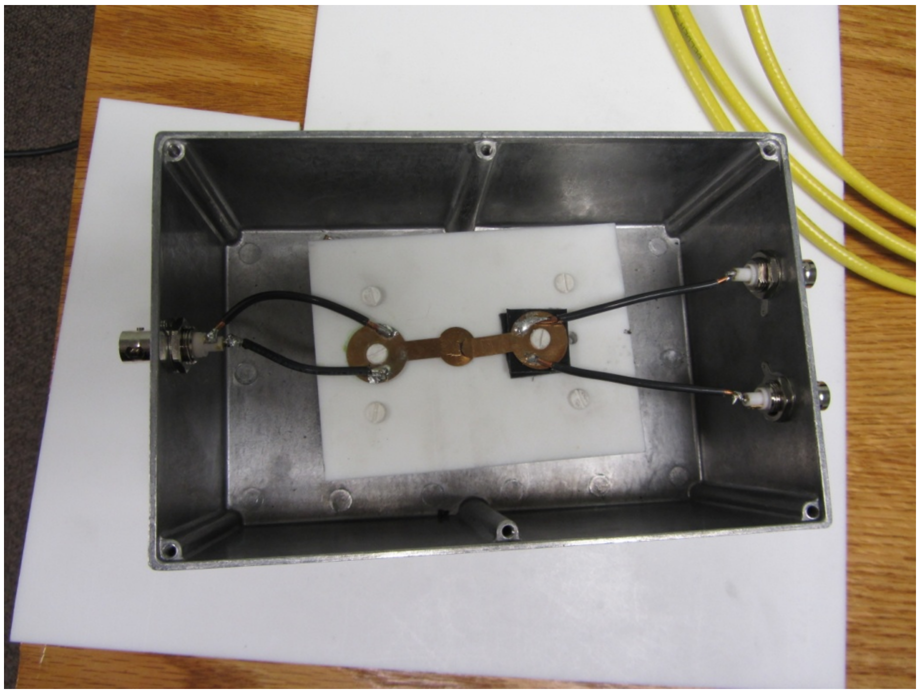
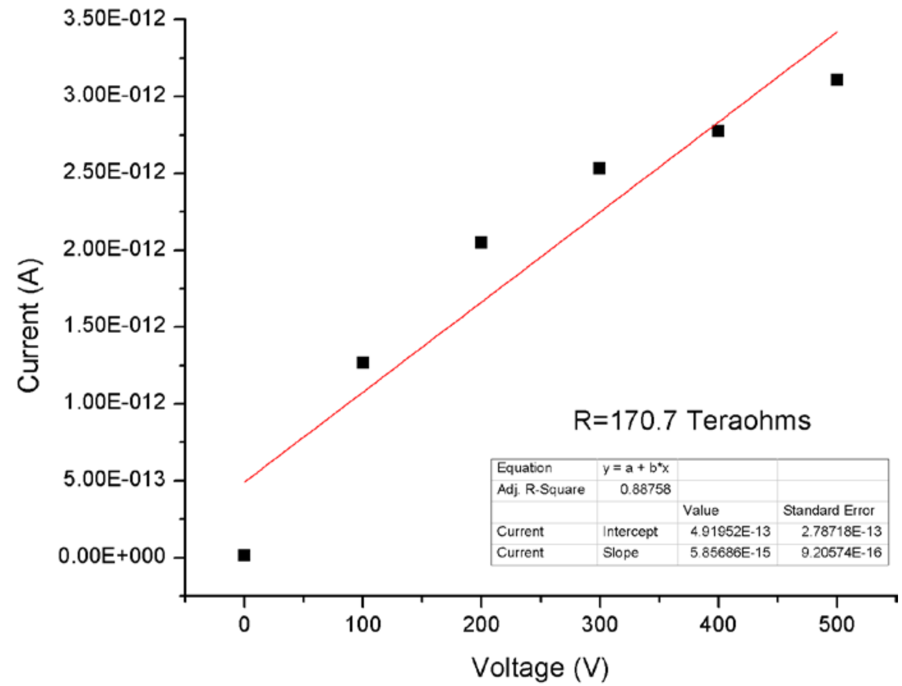
Characterization Progress

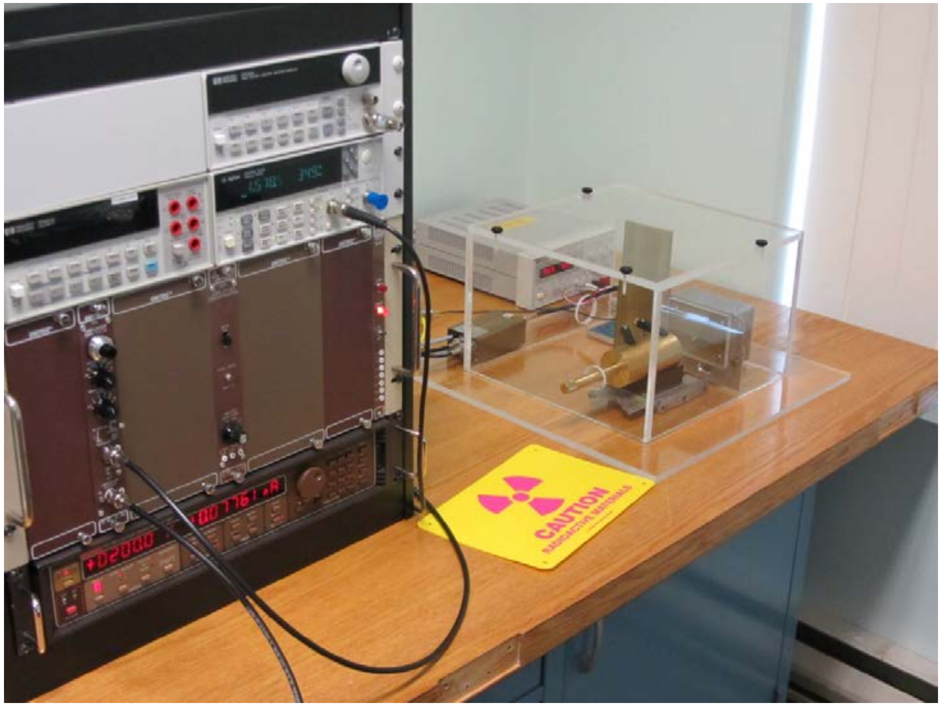
I-V Testing

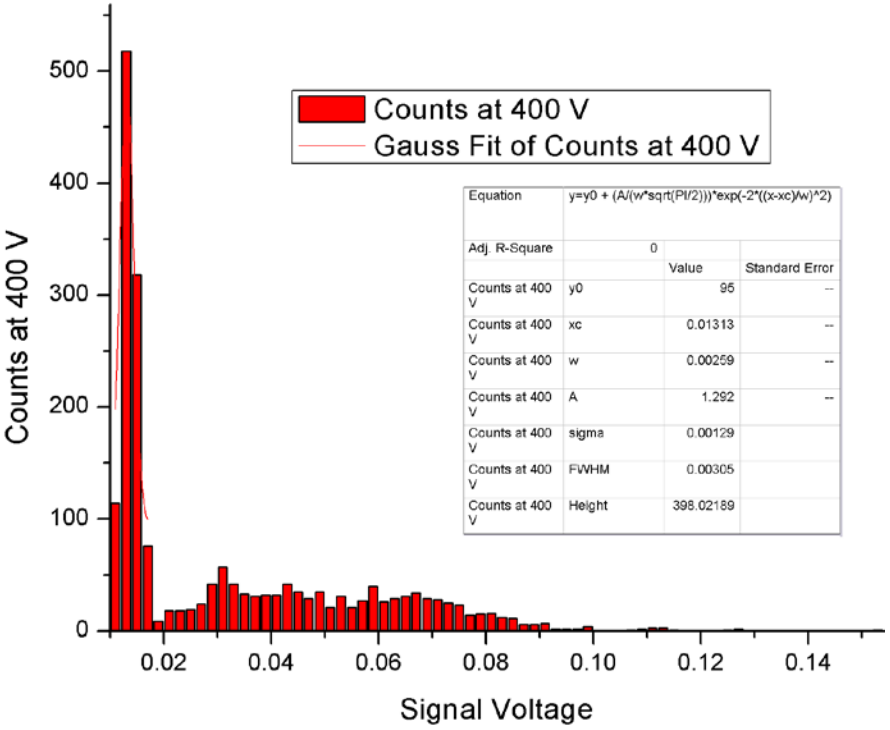




Characterization Progress

Charge Collection Testing

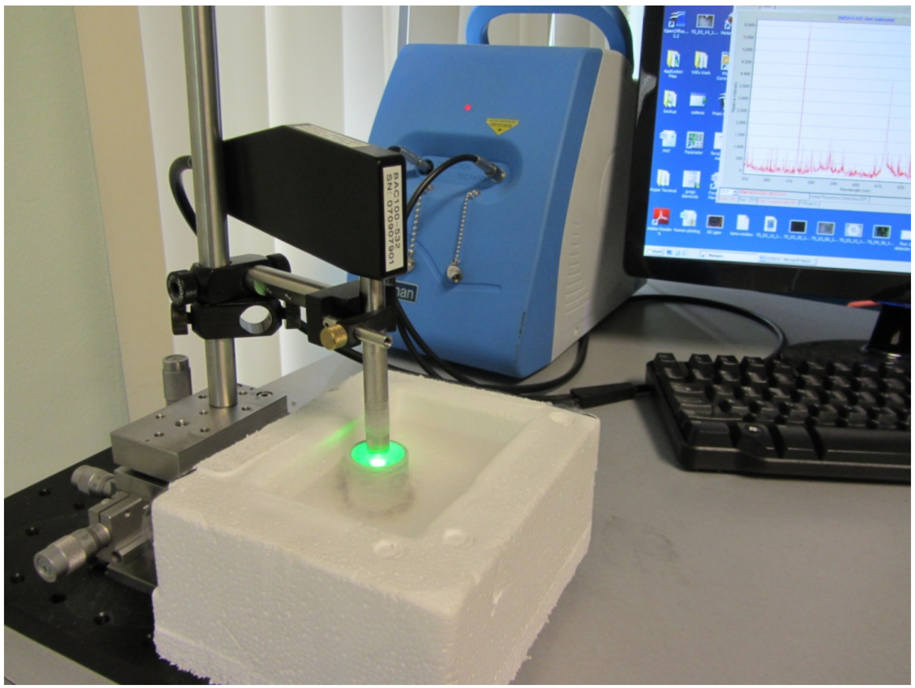


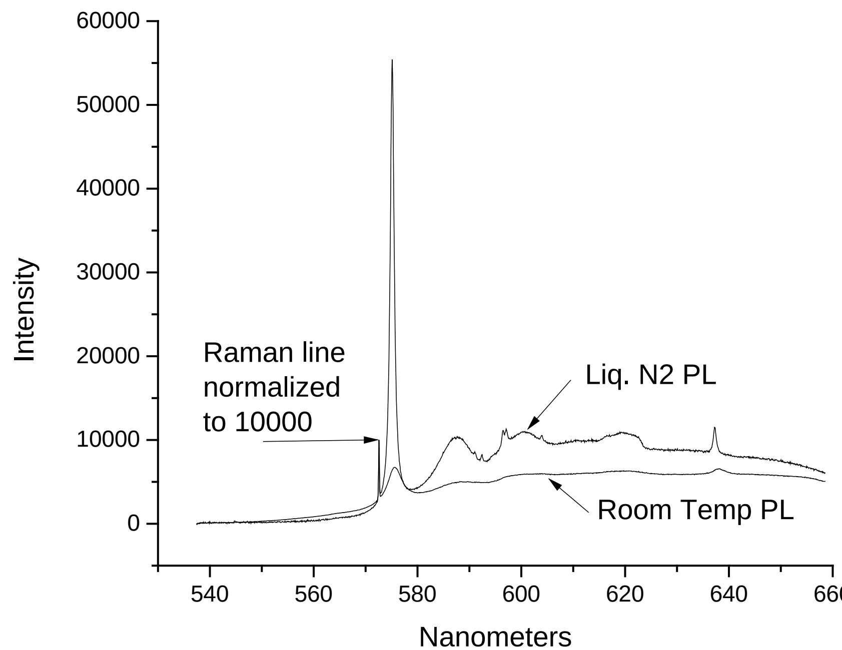


Equation	y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)		
Adj. R-Square	0		
		Value	Standard Error
Counts at 400 V	y0	95	--
Counts at 400 V	xc	0.01313	--
Counts at 400 V	w	0.00259	--
Counts at 400 V	A	1.292	--
Counts at 400 V	sigma	0.00129	
Counts at 400 V	FWHM	0.00305	
Counts at 400 V	Height	398.02189	

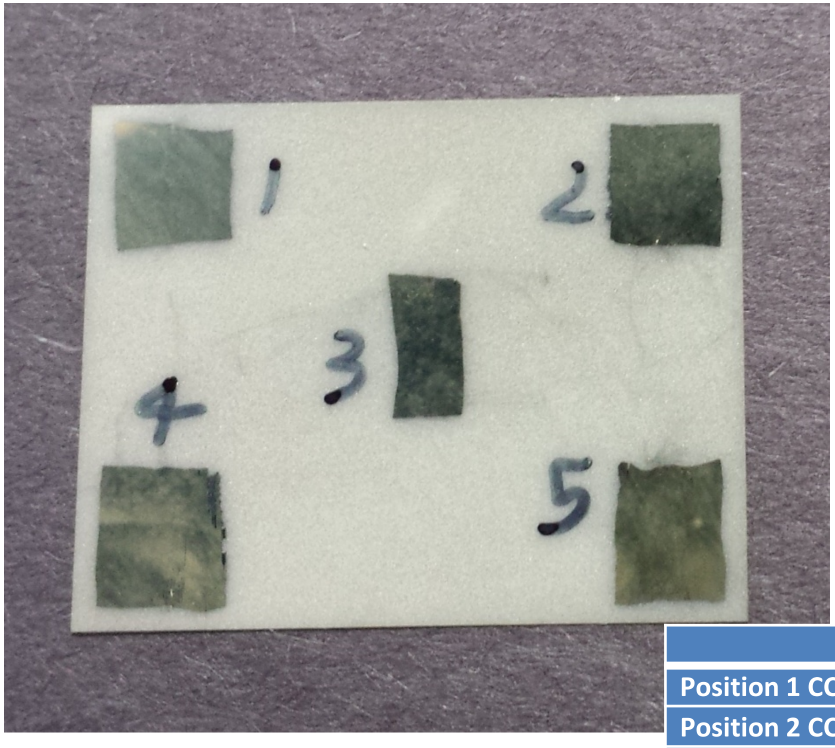
Characterization Progress

cryoPL Testing





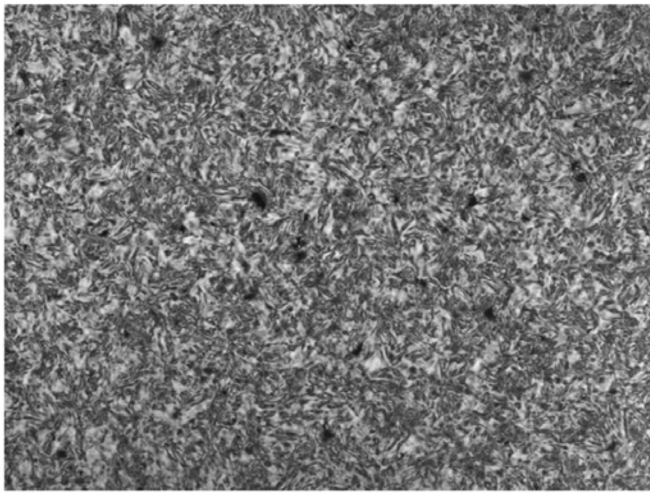
Area Dependence of CCD

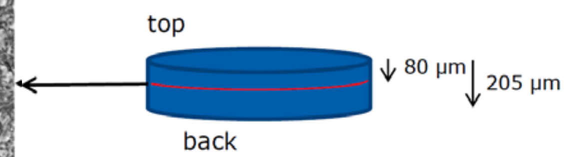


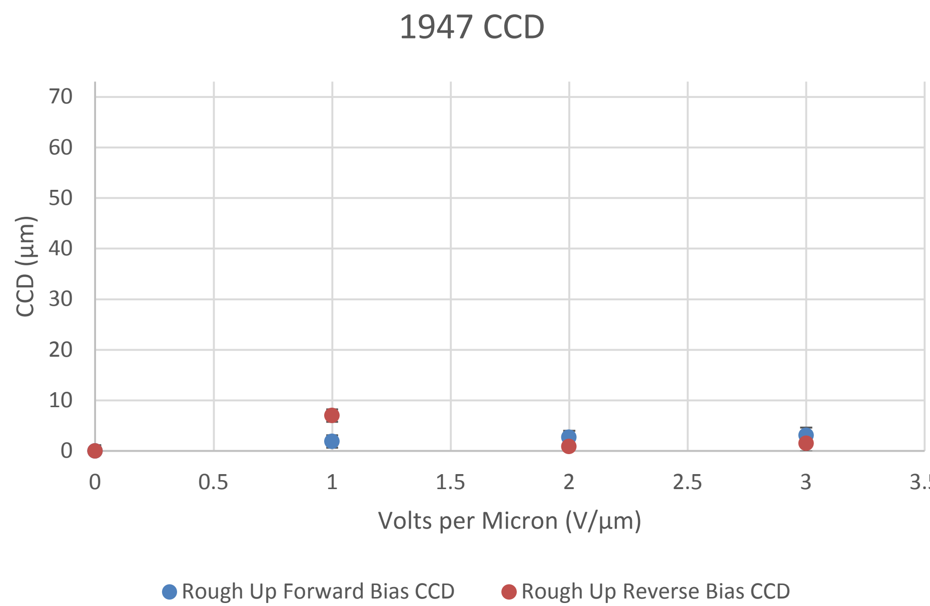
3.71% for forward bias and
3.54% for reverse bias.

	Forward Bias	Reverse Bias
Position 1 CCD (μm)	12.31	12.33
Position 2 CCD (μm)	12.38	11.88
Position 3 CCD (μm)	9.64	9.11
Position 4 CCD (μm)	12.94	12.23
Position 5 CCD (μm)	13.26	12.75
Standard Deviation (μm)	1.28	1.30
Variance (%)	14.92	15.57

Regrowth (Stop/Restart Run)



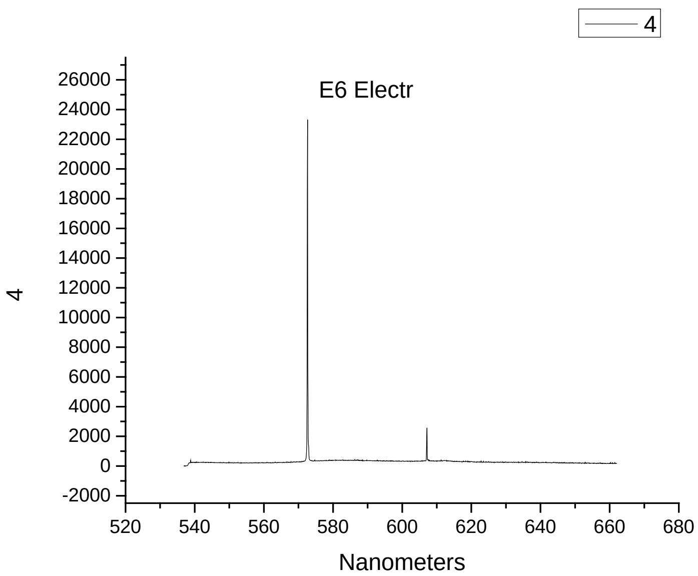


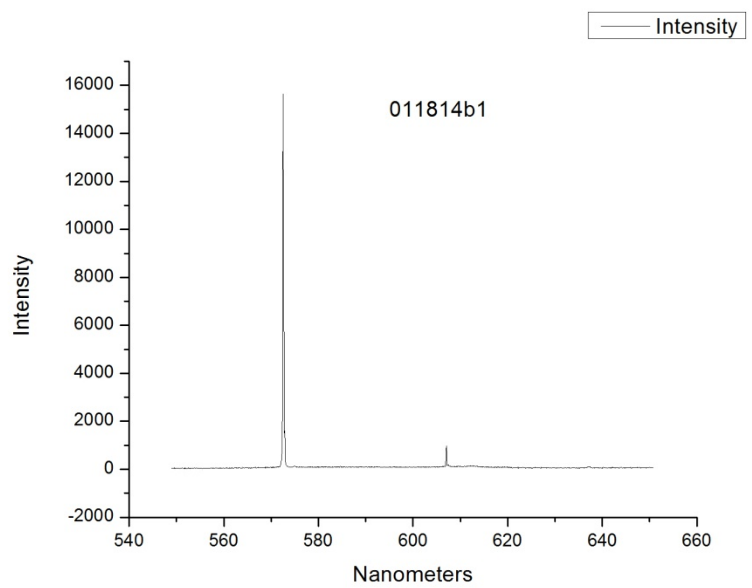


50 μm original thickness
12 μm added

scCVD Growth Progress

- cryoPL shows NV^0 and NV^- approaching benchmark levels





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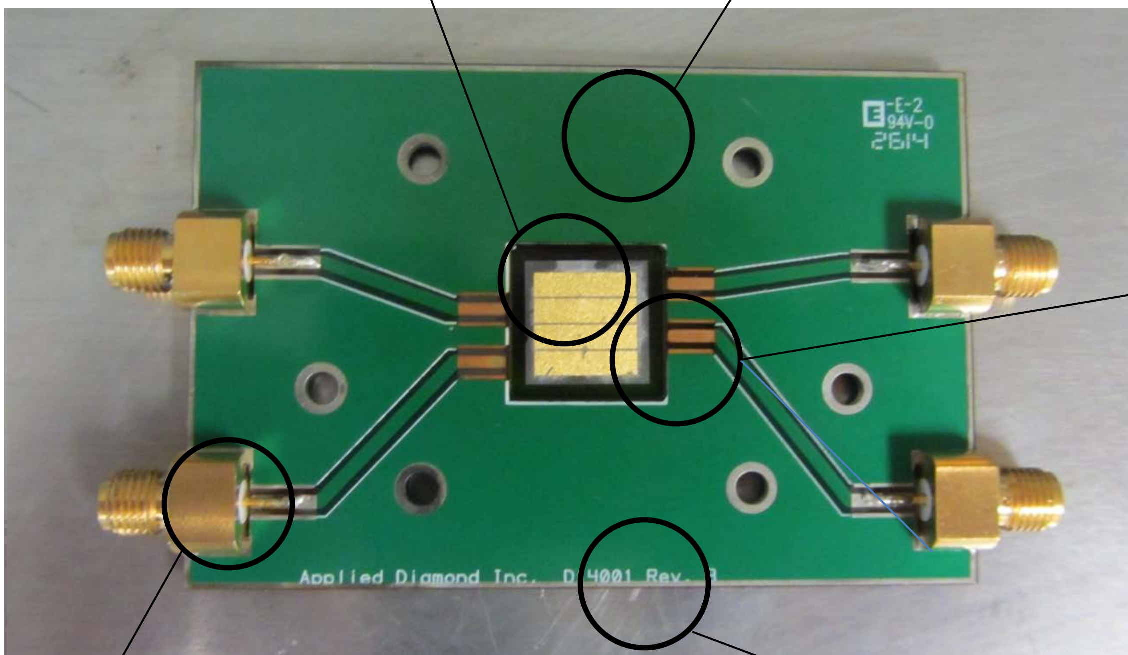
Packaging Progress

PCB design
and build

Lo-res lithography
CrAu contacts

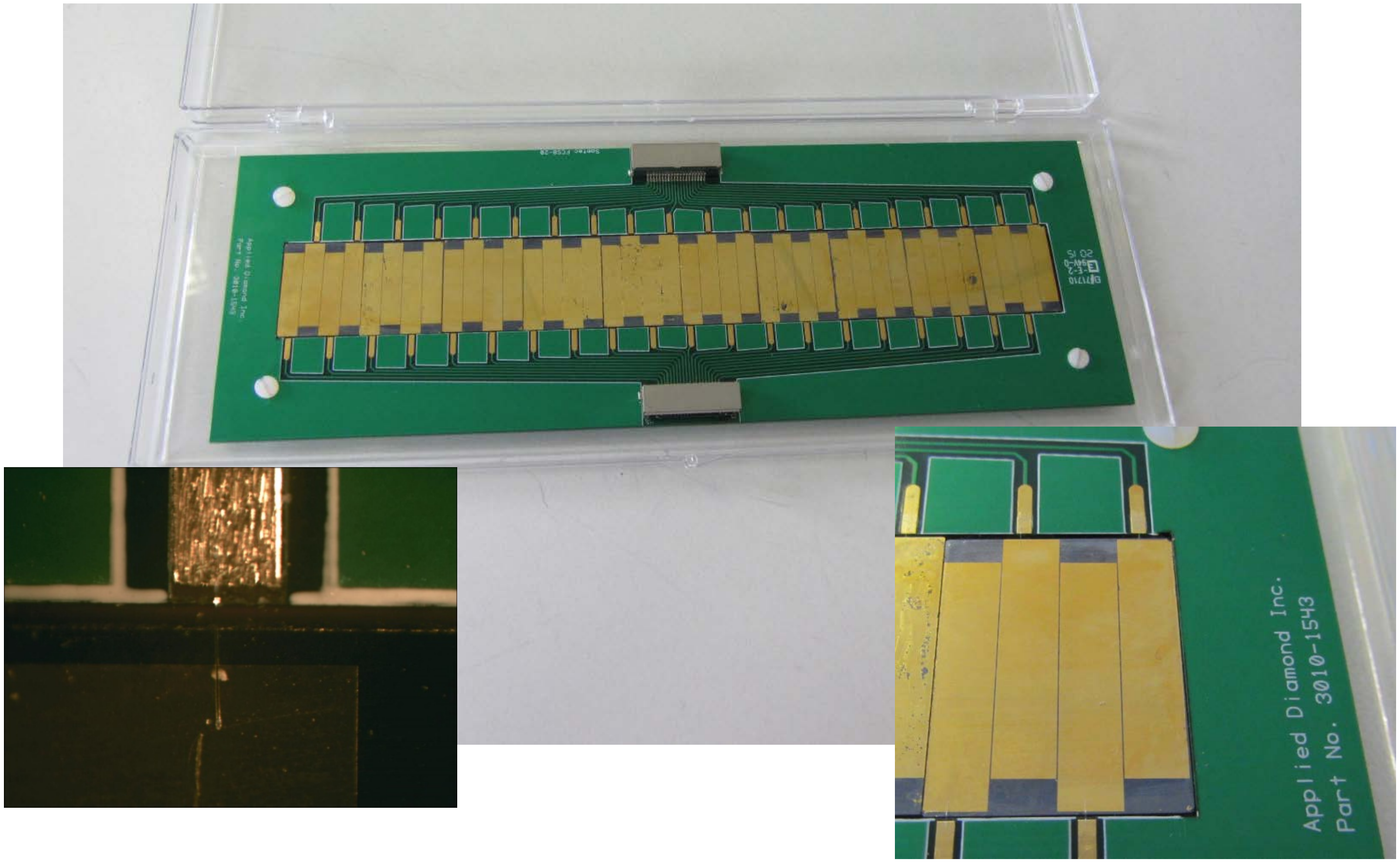


Wire
bonding

Industry-standard
Connectors

Edges sealed with high
vacuum-compatible epoxy

Packaging Progress – Focal Plane Array Board



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Commercialization Strategy

For scientific customers:

- Offer both poly and sc CVD diamond for detector applications
- Develop credibility with results of characterization testing
- Provide standard and custom packaging options
- Partner in development of new detector products

For industrial customers:

- Provide resource to educate and ease adoption of diamond
- Develop one-stop source for detectors using diamond

Current Commercialization Projects

Material Sales

- INFN – 100 electron bunches with 0.5 GeV energies
  - 2 cm sq / 50 μm thick / 5 – 10 μm CCD
- BNL beam position monitors
  - 4.5 mm sq / 50 μm thick / single crystal

Packaged Detectors

- Industrial Partner
  - Neutrons at 14 MeV
- Argonne x-ray fluorescence microscope
  (intensity indicator, normalization of signals collected from samples)
  - 10^{11} photons/sec at 4.5 - 25 keV

Conclusions

- Have a process for growing thin diamond films with predictable charge collection properties.

- Have an analytical method that can reliably predict product performance in customers' applications.

- Have a process for modifying thin diamond coupons to have uniform predictable thickness coupon-to-coupon.

- Have an in-house low volume custom packaging capability.

- Sales of diamond material and prototyping of packaged detectors with end-users have started.

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