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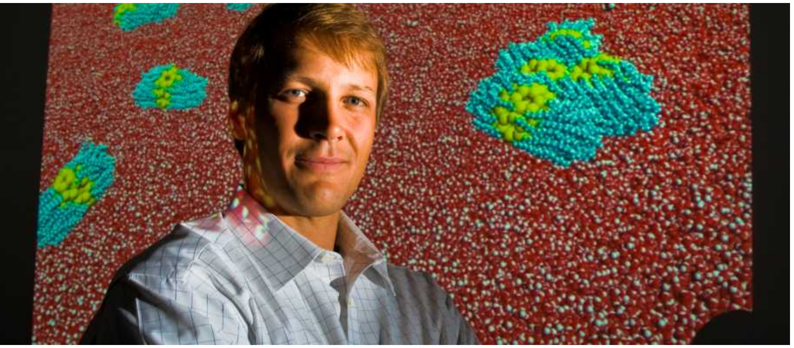
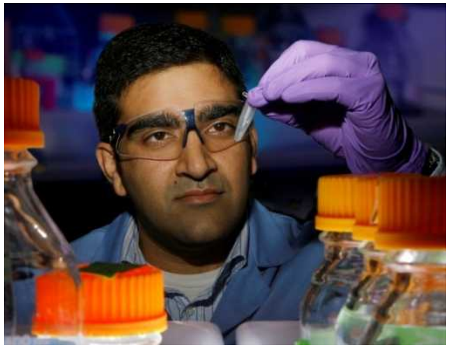
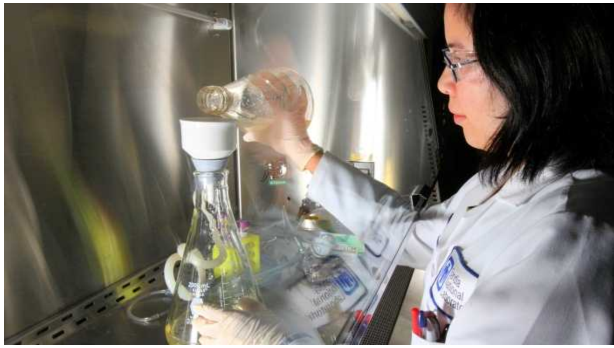


Fabrication of Single Ion Detector in Diamond

B. Aguirre, J. B. S. Abraham, J. L. Pacheco, D. Ward, E. Bielejec and R. Camacho

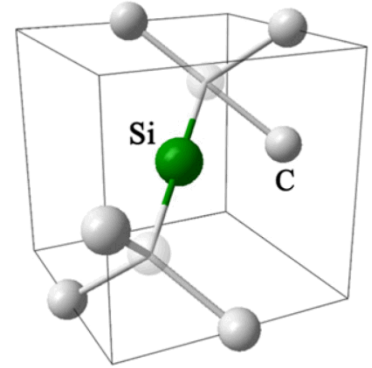
Sandia National Laboratories, Albuquerque, NM

RGSAM October 2nd 2015, Albuquerque NM

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Why Color Centers in Diamond?

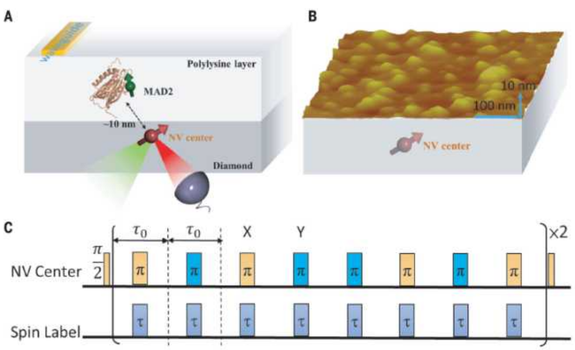
- Color centers (defects) in diamond have been used in a range of application from metrology to quantum computation



SiV in diamond

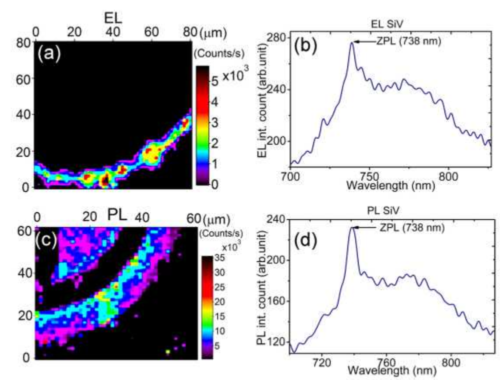
I. Aharonovich *et al.*, Rep. Prog. Phys. **74**,076501 (2011)

Single-protein spin resonance



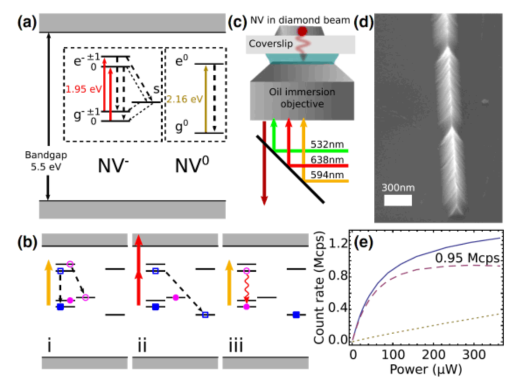
F. Shi *et al.*, Science **347**, 1135 (2015)

Electrically driven SiV



A. M. Berhane *et al.*, APL **106**, 171102 (2015)

Readout of single NV spin



B. J. Shields *et al.*, PRL **114**,136402 (2015)

- Range of defects → NV^-, SiV^-, plus many more in diamond

- Key question → How to produce a ***single*** color center ***where*** you want it?

1.) Location

2.) Yield

We will use ***focused ion beam implantation*** and ***single ion detectors*** to determine both yield and location with high accuracy

Focused Ion Beam (FIB) Implantation

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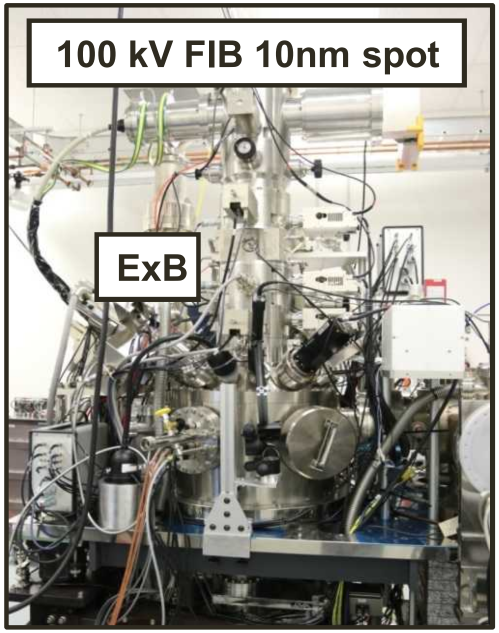
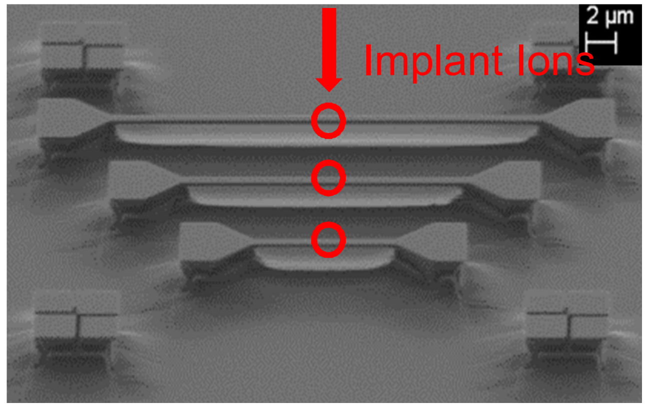
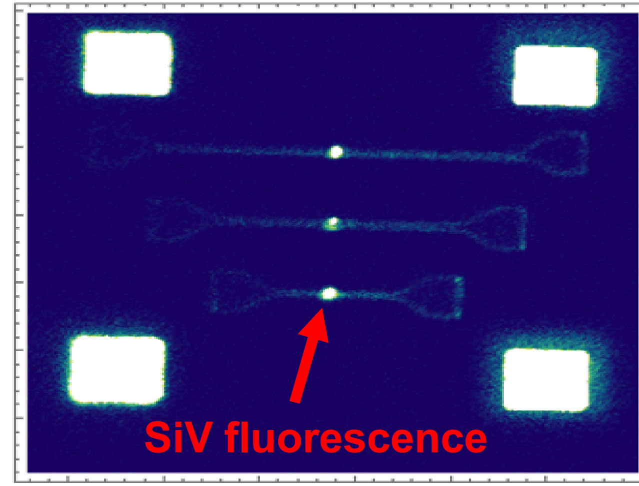
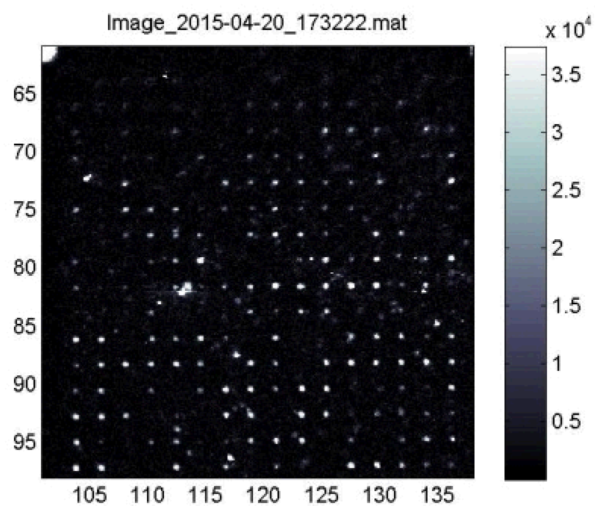


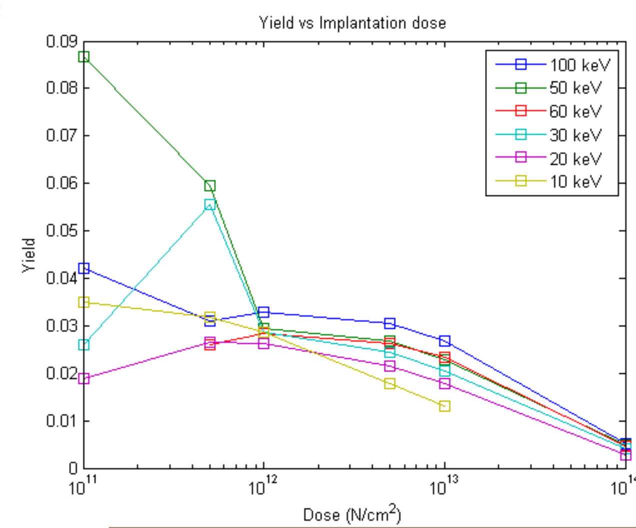
Location (SNL/Harvard collaboration)





Yield (SNL/MIT collaboration)





SNL NanoImplanter (nI)

- Variable Energy 10 -100 kV
- Single Ion Implantation
- Liquid Metal Alloy Ion Source
- Mass-Velocity Filter (ExB)
- ~nm targeting accuracy

Single Ion Detectors

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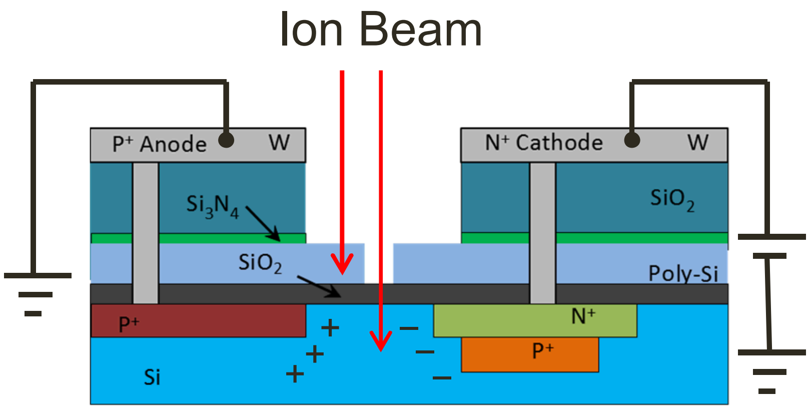
Si Based Detectors



- Use the ionization (e-h pairs) produced during the implant to detect the ion's arrival

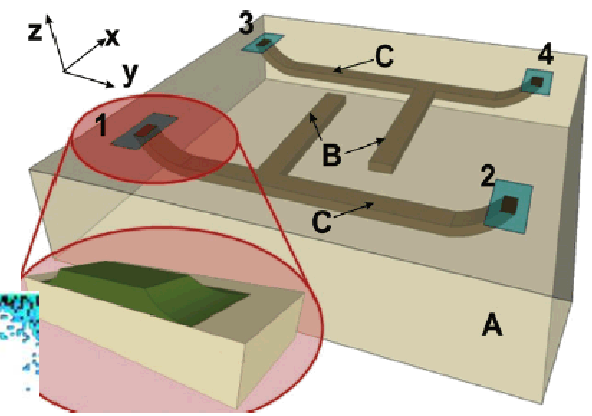
→ Ion Beam Induced Charge (IBIC) collection

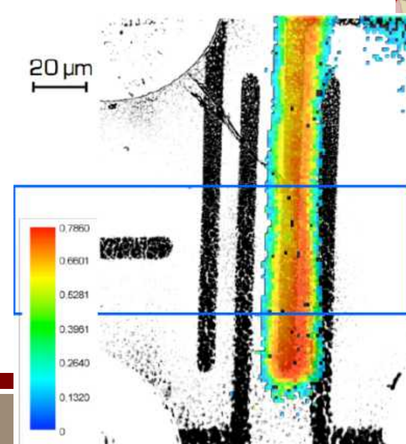
- Si diodes have detected low energy heavy ions with <1000 e-h pair per ion

Diamond Based Detectors

- Issues in diamond:
    - Doping is difficult
    - Bandgap is large

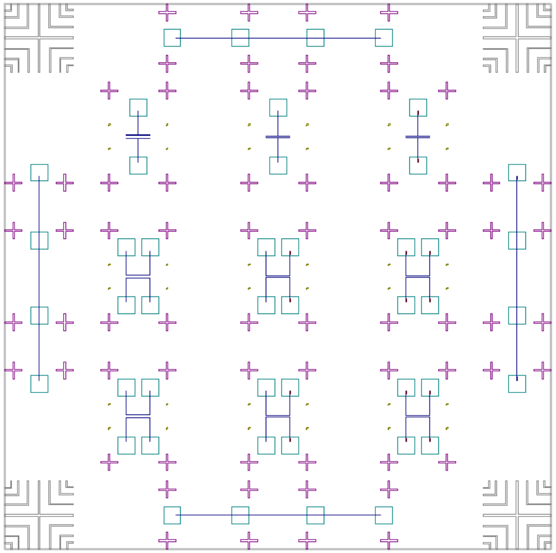
- Graphitized diamond electrodes used for IBIC testing



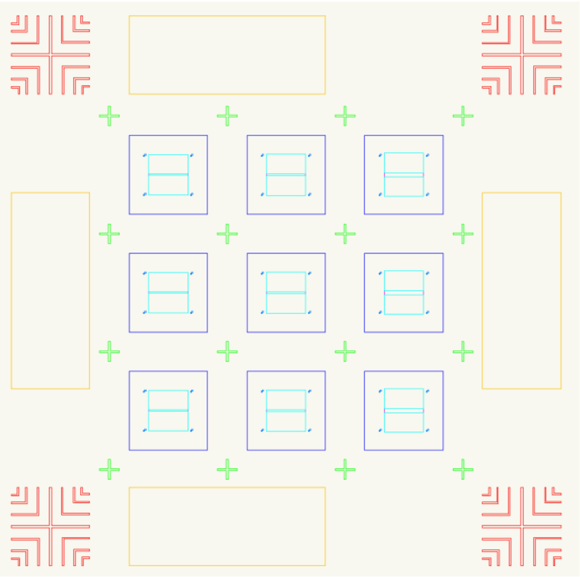


J. Forneris, et al. axXir:1312.4734

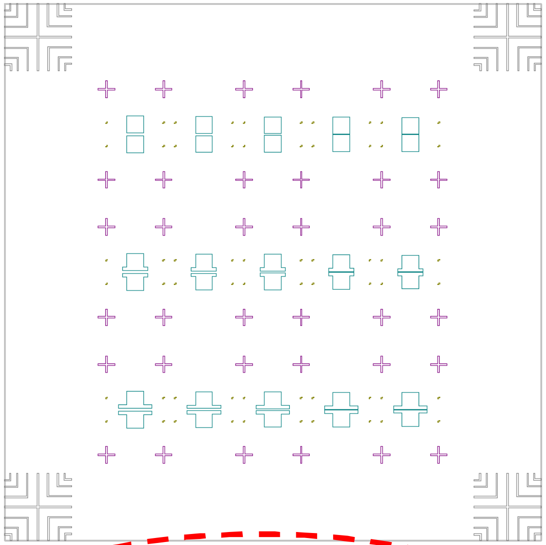
Our detector approaches



Design 1
Graphitized diamond electrodes using the HeIM and nI

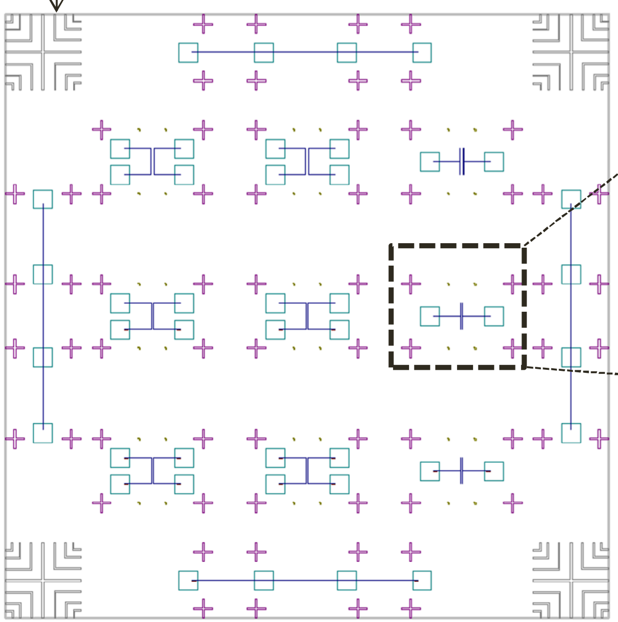


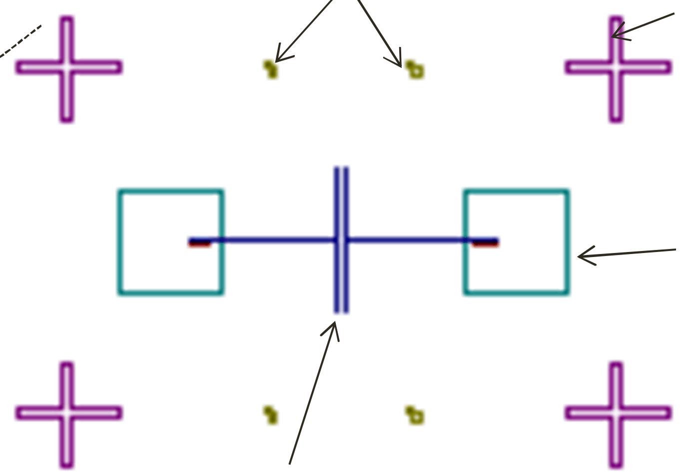
Design 2
Diamond bar detector design simpler approach

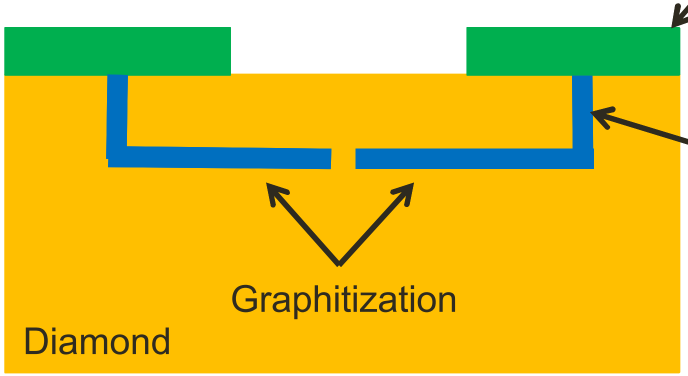


Design 3
Diamond surface electrode detector simplest approach

Design #1 - Graphitized diamond electrodes – using the HeIM and nI







Design # 1 - Fabrication process flow

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Alignment marks

Lithography:

- Sample cleaning
- PMMA spin coating
- Gold deposition (10 nm)
- EBL (Alignment mask write)
- Gold removal
- (PMMA development)

Etching:

- Dry etching

Graphitization

Ion implant:

- PMMA removal
- O2 plasma clean
- HeIM (detector electrodes)
- HeIM (connector channels)
- O2 plasma clean
- Annealing (950 C)

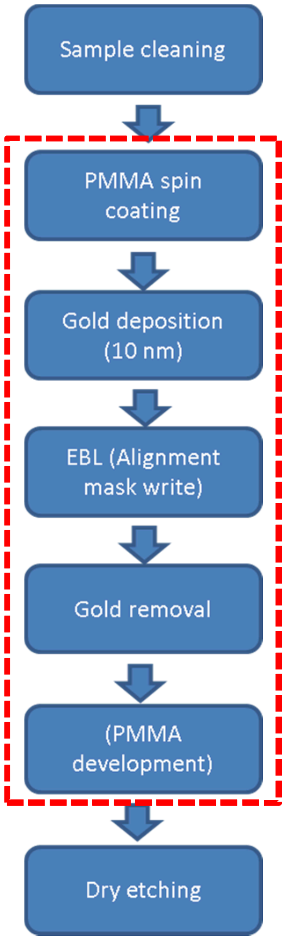
Metallization:

- EBL/Metallization

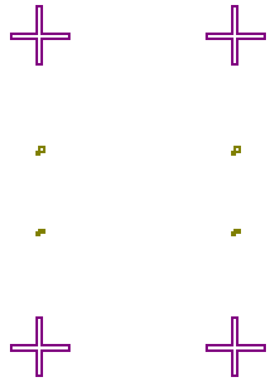
Design # 1 Alignment marks (Lithography)

Sandia National Laboratories

Alignment marks

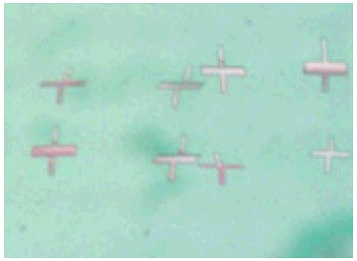


Mask for alignment markers



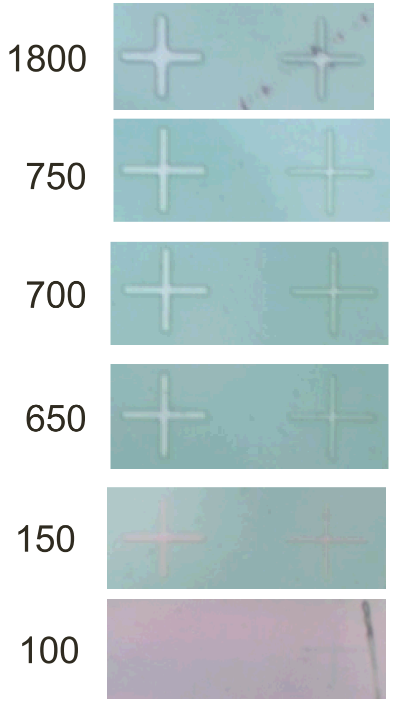
PMMA charging during EBL

Without gold conductive layer



With gold conductive layer

EBL dose test



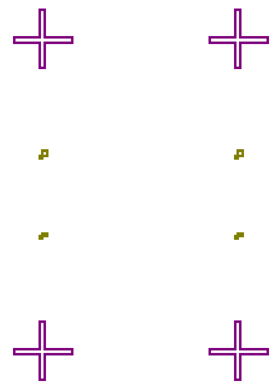
- 10 nm of gold helps to dissipate charge during EBL write
- Dose = 700 μC/cm^2 good for our pattern

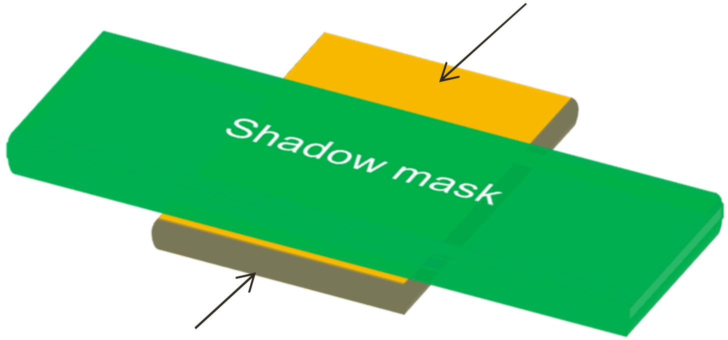
Design # 1 - Alignment marks (Etching)

Alignment marks

- Sample cleaning
- PMMA spin coating
- Gold deposition (10 nm)
- EBL (Alignment mask write)
- Gold removal
- (PMMA development)
- Dry etching

Alignment marks

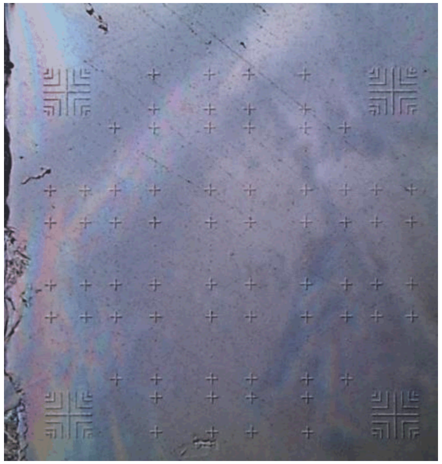




Requirements:

- Sustain high temperatures
- Use of PMMA as masking material
- Visible to HeIM and nI
  - ~100 nm deep

	etch rates (nm/min)	
Material	**Ion milling**	**RIE**
PMMA	40-48	640
Diamond	4.3	7.6



- A 450 nm-thick PMMA (495 C6) will allow us to etch ~ 50 nm of diamond using ion milling
- A 1200 nm-thick PMMA (495 C9) will allow us to etch ~ 116 nm of diamond for alignment marks using ion milling

Design #1 – Ion implant

- Graphitization

PMMA removal

↓

O2 plasma clean

↓

HeIM (detector electrodes)

↓

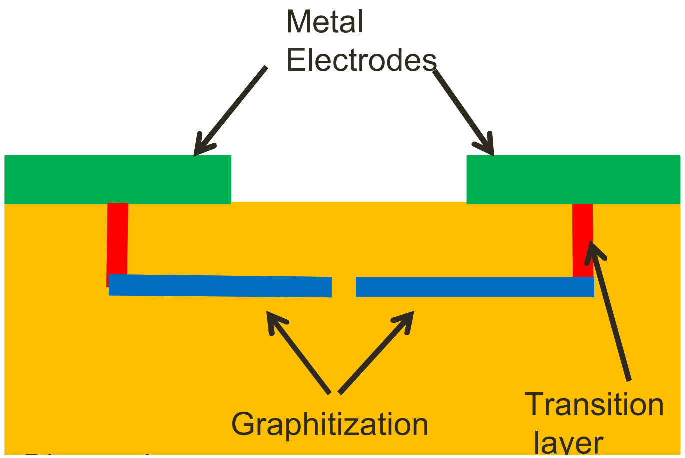
HeIM (connector channels)

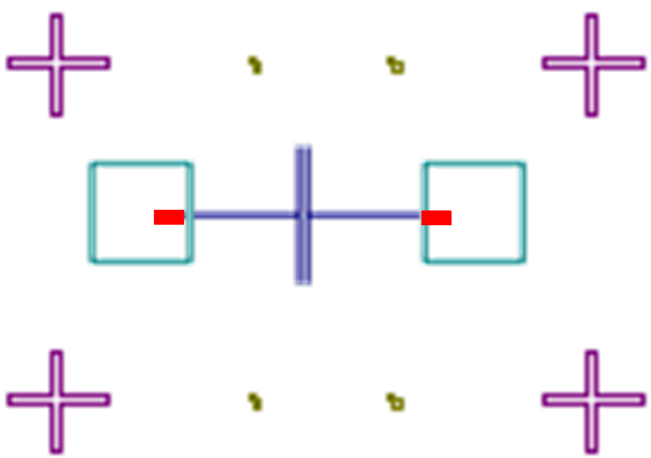
↓

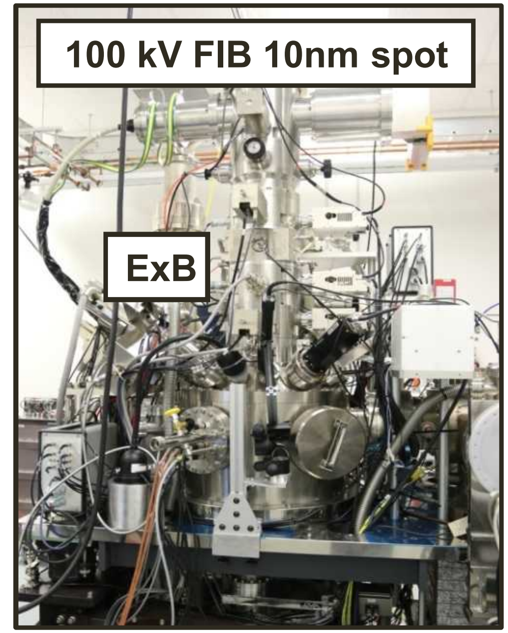
O2 plasma clean

↓

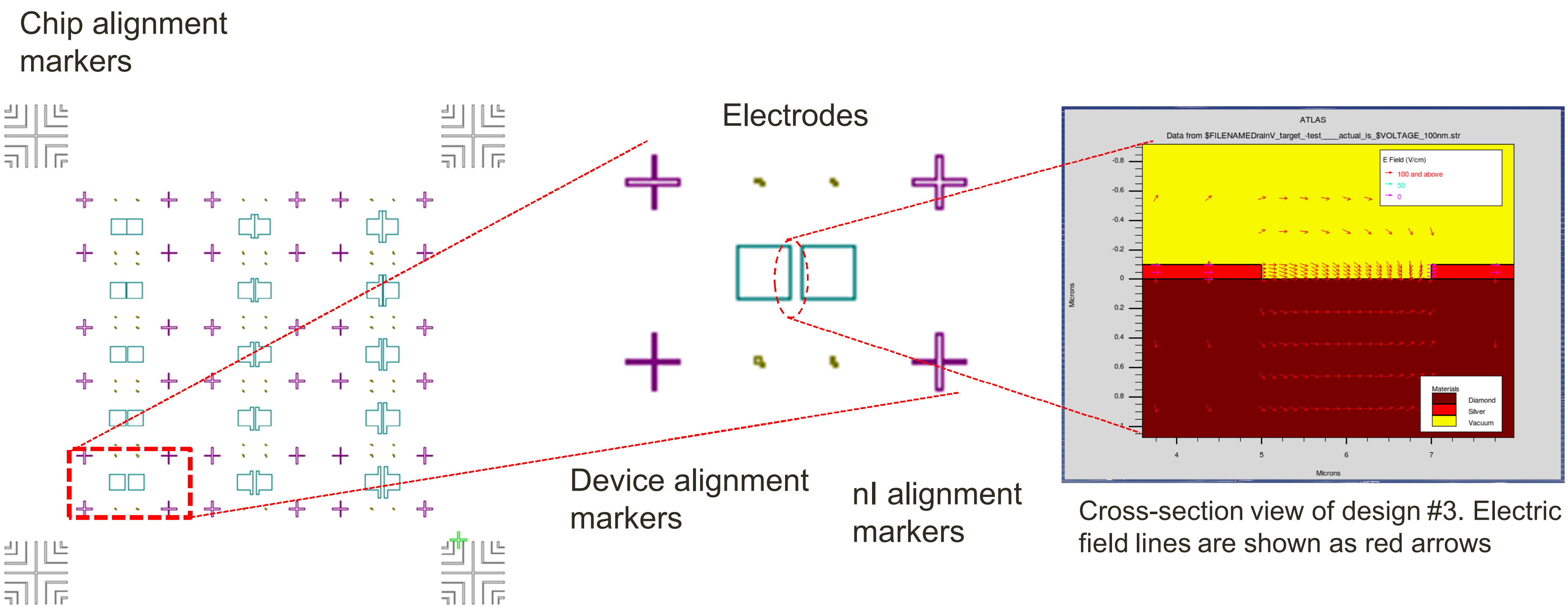
Annealing (950 C)





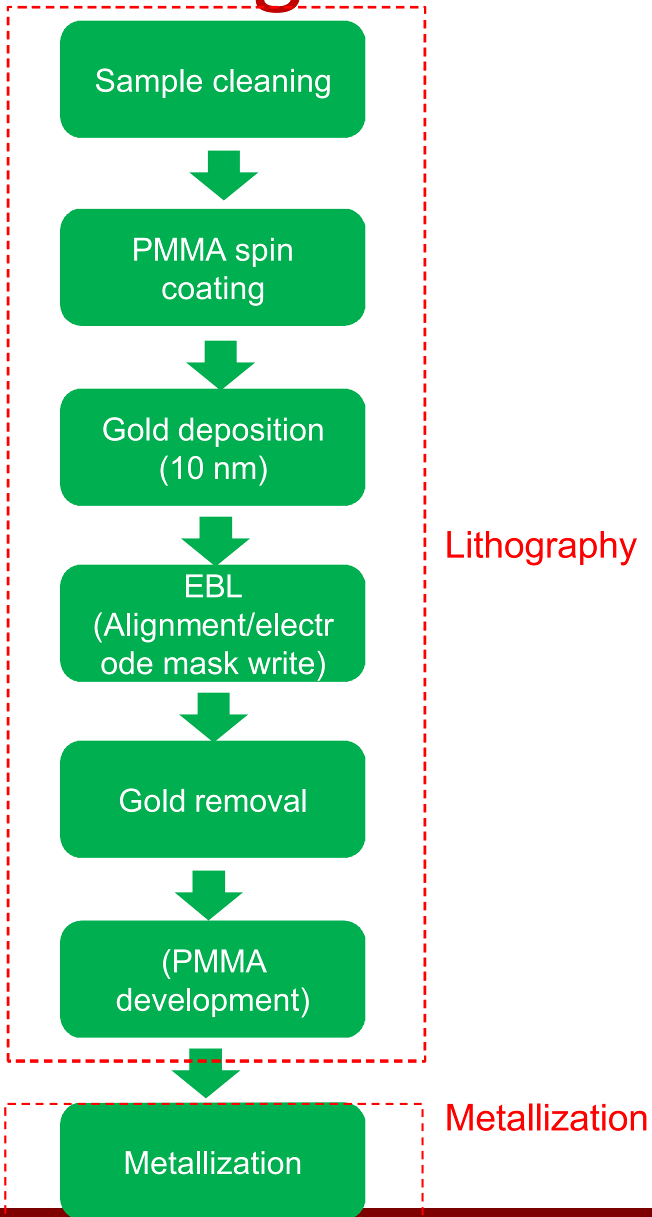


Design #3 - Diamond surface electrode detector



Cross-section view of design #3. Electric field lines are shown as red arrows

Design # 3 - Fabrication process flow



Design # 3 fabrication results to-date

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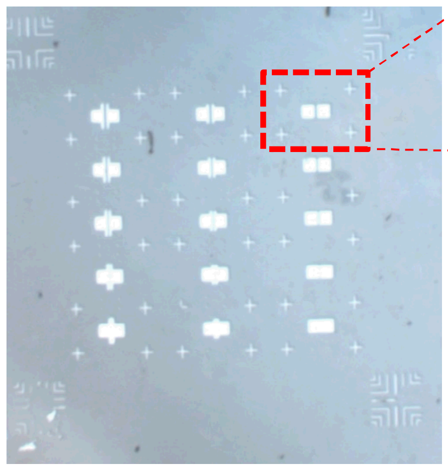
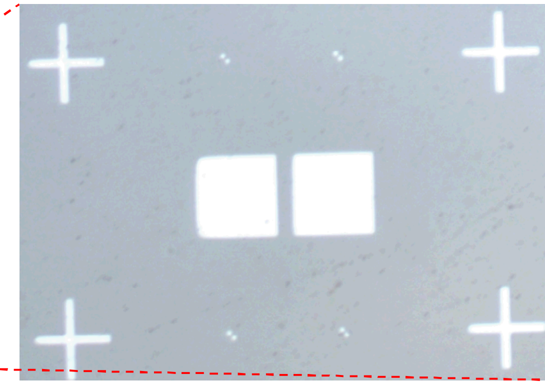
- Sample cleaning
- PMMA spin coating
- Gold deposition (10 nm)
- EBL (Alignment/electrode mask write)
- Gold removal
- (PMMA development)
- Metallization
- Lift-off

- <u>Alignment markers</u>
  - Metal markers work for this design
  - Metal electrode (Ag)
  - Visible to HeIM and nI





<u>Metallization:</u>
- Electron beam deposition
- 100 nm of Silver
- Dep rate: 2 A/sec

<u>Lift-off</u>
- Remover PG @ 80 C

- Ag metal electrodes and alignment marks were successfully deposited on diamond substrates
- Next step is to perform IV, CV and IBIC, measurements as a function of gap spacing and electrode size

Future directions

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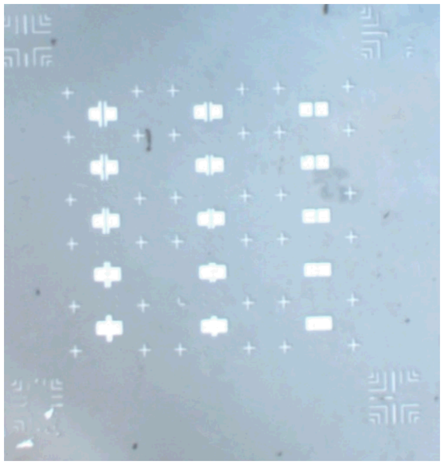
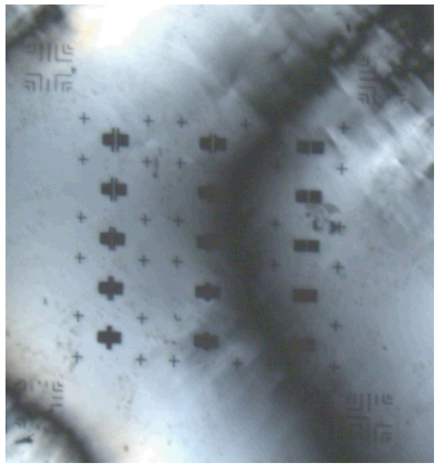
Correlate surface defects to electrical behavior

- DIC microscopy (subsurface damage)
- AFM (surface roughness)



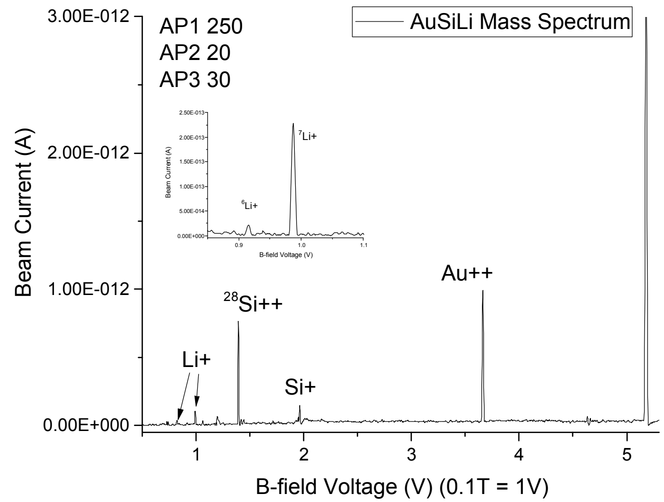


Spectroscopy studies

- PL

Perform IBIC measurments

- Single ion detection using Li ion beam



Conclusions

Fabrication:

Design #1 Graphitized diamond electrodes detector
- Developed fabrication process for chip, device and IBIC characterization-level alignment marks

Design #2 Surface electrode detector
- Fabricated simple structure on diamond to perform electrical and spectroscopy tests on diamond

Characterization:

- Li ion beam source developed for IBIC measurements