edge-Transient Current Technique in single crystal CVD diamonds

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Outline

- Background
- Experimental setup
- Results
- Analysis
- Simulation
- Conclusions
edge-TCT (concept)

- Powerful tool to demystify the charge transport properties of (irradiated and unirradiated) sCVD diamond:
  - electric field (independently of trapping) $\rightarrow$ space charge
  - trapping times
  - saturated velocity
  - mobility electrons and holes
Electronic band gap of diamond

**Indirect Bandgap**
required energy $\approx 5.47 \text{ eV} / 226 \text{ nm}$
(minus phonon contribution and exciton energy)
1-photon absorption
2-photon absorption: $E_\gamma \approx 2.74 \text{ eV} / 453 \text{ nm}$

**Direct Bandgap**
required energy = $7.3 \text{ eV} / 170 \text{ nm}$
1-photon absorption
2-photon absorption: $E_\gamma = 3.65 \text{ eV} / 340 \text{ nm}$
3-photon absorption: $E_\gamma = 2.43 \text{ eV} / 510 \text{ nm}$

**Attoline Laser**
- $\approx 25 \text{ fs}$
- $0.1 – 5 \text{ nJ pulse energy, equivalent to } 2 \times 10^8 – 10^{10} \text{ photons/pulse}$
- photon energy of $3.1 \text{ eV} (400 \text{ nm})$
2-Photon Absorption

- Theoretically predicted in 1931 by Maria Goppert Mayer in her Ph.D. thesis at Göttingen
- Experimentally observed in CaF$_2$:Eu$^{2+}$ by Kaiser and Garret at Bell Labs in 1961
Setup

- Pulse length — 25 fs
- Pulse energy — 0.1 nJ - 5 nJ
- Laser wavelength — 800 nm
DAQ screenshot

Main DAQ

webcam

All running in Linux.

Software 100% remote controllable
scCVD sample

- bought from Element 6 (through DDL)
- Not used in PLT due to poor CCD performance
  - requires high field to collect full charge
- thickness — 566 µm
- Not irradiated
- pad metallized by Rutgers University (TiW sputtered with shadow mask)
- metallization distance from edge ≈400 µm
- 2 edges polished
Beam profile

- Beam profile from the knife edge scan
  - in air, not accounting for aberration in diamond
  - 2.0 mm => 4.8 mm

- The charge profile is proportional to intensity squared for 2 photon absorption
2016: The first waveform was measured at 400 nm. Only 2/3 PA could allow this (theoretically).
1st 3D scan

Test parameters:
- Bias voltage: -400V (0.7 V/µm)
- 50 waveform averaging, 3993 scan points (~0.4s each)
- Laser pulse energy: 0.2 nJ

Parameters to extract:
- drift speed
- electrical field configuration
  - space charge
- trapping rate
Waveform analysis

- **Total charge**
  - Integral of the complete baseline corrected waveform

- **Prompt current**
  - 0.3 ns-Integral around the center of the rising edge

- **Prompt current** is proportional to the electric field at the focal point
  - Possible to extract space charge distribution
Total charge

Approximate focal position: 1.0 mm (from front edge)

Charge Profile at x=-10.5mm

Charge Profile at x=-9.2mm
Prompt current

Approximate focal position: 1.0 mm (from front edge)

Prompt current profile at $x = -9.0$ mm

Prompt current profile at $x = -8.0$ mm
Electric field

Approximate focal position: 1.0 mm (from front edge)

Electric field profile at x = -9.0 mm

Electric field profile at x = -8.0 mm
Detector simulation with KDetSim

- Simulation allows to model signal’s shape
- Injection along a laser beam line
- No space charge
- Diffusion = on
- No RC filter, no trapping
- holes ≈ 7.7 µm/ns
- electrons ≈ 5.8 µm/ns
Detector simulation with KDetSim

- Injection along a laser beam line
- No space charge
- Diffusion = on
- No RC filter, no trapping
- holes $\approx 7.7 \ \mu\text{m/ns}$
- electrons $\approx 5.8 \ \mu\text{m/ns}$

Closer to the metallization end effects due the non-uniform electric field become apparent.
Detector simulation with KDetsim

- Injection along a laser beam line
- No space charge
- Diffusion = on
- No RC filter, no trapping
- holes \(\approx 7.7 \, \mu m/\mu s\)
- electrons \(\approx 5.8 \, \mu m/\mu s\)

Closer to the metallization end effects due the non-uniform electric field become apparent
Detector simulation with KDetSim

- Another way to modify the signal shape is with the space charge
- Cubic space charge distribution
- Injection along a line
- Diffusion = on
- No RC filter, no trapping

Toy space charge model

Very preliminary!

slowly falling

y=450μm

y=50μm

Very preliminary!
Conclusions

- We have a working edge-TCT setup for investigating charge transport properties in scCVD diamonds
- Clear TCT signals have been observed
- We are making the first steps in the analysis and simulation
Outlook

• Introduce a shutter in the setup for on demand automatic light blocking
  - understand systematics due to light pumping
• Better understand the shape of the focal point in diamond
• Try lenses with different focal strengths
• Measure diamond with strip metallization pattern
New setup in Johnson lab

- Oscilloscope
- DAQ PC
- xyz-stage
- xyz-stage control
- high voltage supply
- LV supply
- Amplifier
Electric field calculations

\[ I_{e,h} = A \cdot e_0 \cdot N_{e,h} \cdot e^{-\frac{t}{\tau_{eff}}} \cdot v_{e,h} \cdot W \]

\[ I_{e,h}(t = 0) = A \cdot e_0 \cdot N_{e,h} \cdot \mu_{e,h}(E) \cdot E \cdot \frac{1}{d} \]

\[ I_{e,h}(t = 0) = \text{constant} \cdot \mu_{e,h}(E) \cdot E \]

0 = \[ I_{e,h}(t = 0) \]

Use ‘Bisection Method’ to solve for \( E \) with the constraint that:

\[ V_{Bias} = \int_0^d E \, dy \]
Bisection method

LOOP

evaluate $f(a)$, $f(b)$, $f(c)$

if $f(a) \times f(b) > 0$:
    $a = (a+c)/2$
else:
    $c = (a+c)/2$

if $|a - c| < \text{threshold}$:
    found solution
• Simulation of focal point in air.
  - Interference patterns due to thin lens approximation.
  - Thin lens filled with beam causes airy discs.

Simulation of focal point in diamond (Intensity)

- $y=40\mu m$
- $y=50\mu m$
- $y=60\mu m$
- $y=70\mu m$