Conductivity Study of CVD-diamond detectors

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Contributing...

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Outlines

- Introduction
- $I-V$ characteristics of CVD Diamond Detectors
- Dark conductivity study of CVD Diamond materials
  1. Homoepitaxial CVD Diamonds, both sc and sc coating with DLC
  2. Heteroepitaxial quasi sc CVD Diamond on Ir (DoI)
- Summary
Introduction

Electrical Conductivity

Electrode-Limited conduction

1. Schottky (Thermionic) emission
   (i) Direct Tunneling (DT)
   (ii) Fowler Nordheim (FN)

2. Tunneling

Bulk-Limited conduction

1. Space-charge limited conduction (SCLC)
2. Poole-Frenkel (P-F) conduction
3. Trap Assisted Tunneling (TAT)
**Diamond Detectors**

Diamond

Diamond Detectors
Measurement setups

- Diamond Detectors
- Diamond Detector Electrodes
- Ceramic
- Temperature Sensors
- Electrodes
**I-E characteristics CVDD Detectors**

![Graph showing I-V characteristics](image-url)

- **DARK CURRENT [A]**
  - $-8 \times 10^{-13}$
  - $-4 \times 10^{-13}$
  - $0$
  - $4 \times 10^{-13}$
  - $8 \times 10^{-13}$

- **$E_D$ [V/µm]**
  - $-6$
  - $-5$
  - $-4$
  - $-3$
  - $-2$
  - $-1$
  - $0$
  - $1$
  - $2$
  - $3$
  - $4$
  - $5$
  - $6$
  - $7$

- **Lines and markers**
  - sc-CVDD_45 Ph-II (100µm)
  - Dol 549a (230µm)
  - 724b (12µm)
  - 886-1 (290µm)
  - 886-2 (320µm)
Electrical conduction of scCVDD

\[ \text{scCVDD 10B50 (50\,\mu m)} \]
\( (\text{Al-Dia-Al}) \)

\[ I^{-}V \text{ characteristics at higher temp} \]

\[ I^{-}E \text{ characteristics, SCLC} \]
Space Charge Limited Conduction (SCLC)

$\text{sc37}_113\mu m (\text{Al/DLC-Dia-DLC/AL})$

**Theory of SCLC**

$$I_{\text{Child}} = \frac{9}{8} \mu \varepsilon \frac{V^2}{d^3}$$

$$I_{\text{TFI}} = \frac{9}{8} \mu \varepsilon \theta \frac{V^2}{d^3}$$

Here,

- $\mu$ electronic mobility
- $V$ applied bias
- $d$ thickness
- $\varepsilon$ dielectric constant
- $\theta = \frac{\text{_free Carrier Density}}{\text{Total Carrier Density}}$

**Diagram Details**

- **Region I & III**: Child's law
- **Region II**: Trap-filled limited
- $n \approx 2.9$
- $n \approx 5.9$
- $100^\circ C$
- Positive bias
- **Positive Bias**
- **sc-CVDD sc37_113um**
Electrical conduction of scCVDD

**scCVDD 10B50 (50µm) (Al-Dia-Al)**

**scCVDD s256-02-06**

**I-E characteristics, SCLC**

Michal Pomorski
PhD thesis 2008
I-V characteristics of scCVDD with DLC coating

sc37_113µm
(AI/DLC-Dia-DLC/AL)

I-V characteristics at higher temp.
Electrical conduction of scCVDD with DLC coating

\[ J = A^* T^2 \exp \left[ -\frac{q(\phi_b - \sqrt{qE_D}/4\pi\kappa_d\varepsilon_o)}{k_bT} \right] \]

\[ \ln(J/T^2) \propto E_D^{1/2} \]

\[ \eta^2 = K_d \]

Schottky emission (S-E) conduction? NO
Electrical conduction of scCVDD with DLC coating

\[ J = C_i E_D \exp \left[ -\frac{q(\phi_i - \sqrt{qE/\pi\kappa_d\varepsilon_o})}{k_B T} \right] \]

\[ \ln(J / E_D) \propto E_D^{1/2} \quad \eta^2 = \kappa_d \]

Poole-Frenkel (P-F) conduction? NO
Electrical conduction of scCVDD with DLC coating

scCVDD sc37 (113µm)
(AL/DLC-Dia-DLC/AL)

I-E characteristics, SCLC
**$E^{ac}$ of scCVDD with DLC coating**

\[
\ln(I) = A + \frac{E^{ac}}{k_B T} \frac{1}{T}
\]

$E^{ac}$, activation energy

$k_B$, boltzmann constant

$T$, absolute temp.

\[E^{ac} \approx 0.381 \pm 0.017 \text{ eV}\]

\[E^{ac} = 0.441 \sim 0.534 \text{ eV}\]

**scCVDD sc37 _ 113mm (Al/DLC-Dia-DLC/Al)**

Activation Energy of the trap

**13-15 December**

1000/T [K⁻¹]  2nd CARAT Workshop, GSI

Shahinur Rahman

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**I-V characteristics of Early DoI**

**DoI 549a 230µm**

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**Early Results**

**I-V characteristics at higher temp.**
Activation energy of Early DoI

Activation Energy of traps $E_{ac} = 1.53 \pm 0.01$ eV

Ref. $E_{ac} = 1.4$ eV; A. Stolz, et al., DRM 2006
Electrical conduction of early DoI

DoI 549a 230\(\mu m\)

\[ I \propto E^\alpha \]

\( I \), Current [A]  
\( E \), Field [V/\(\mu m\)]

\( \alpha = 1.77 \)
\( \alpha = 1.39 \)
\( \alpha = 1.58 \)
\( \alpha = 1.22 \)
\( \alpha = 1.55 \)
\( \alpha = 1.70 \)
\( \alpha = 1.02 \)
\( \alpha = 1.24 \)
\( \alpha = 0.9 \)
\( \alpha = 0.66 \)
\( \alpha = 0.3 \)
\( \alpha = 0.28 \)
\( \alpha = 0.66 \)

I-E characteristics  Dark conductivity ??
Electrical \((I-E)\) Characteristics of DoI

Dol 886-1 290\(\mu\)m

I-V characteristics at higher temp.
Electrical conduction of DoI

\[ J = A^* T^2 \exp \left[ -\frac{q (\phi_b - \sqrt{qE_D/4\pi\kappa_d\varepsilon_o}}{k_b T} \right] \]

\[ \ln(J/T^2) \propto E_D^{1/2} \quad \eta^2 = \kappa_d \]

**Schottky emission (S-E) conduction? NO**
Electrical conduction of DoI

\[ J = C_i E_D \exp \left[ -q(\phi_i - \sqrt{qE/\pi\kappa_d\varepsilon_o}) \frac{k_b T}{k_b T} \right] \]

\[ \ln(J / E_D) \propto E_D^{1/2} \quad \eta^2 = \kappa_d \]

\[ n = 0.3053 - 0.3421 \]

Poole-Frenkel (P-F) conduction?

\[ n = 0.4849 - 0.621 \]

NO
Electrical conduction of DoI

DoI 886-1 290µm

I-E characteristics, SCLC
Electrical conduction of DoI

\[ \ln(I) = A + \frac{-E^{ac}}{k_b} \cdot \frac{1}{T} \]

- \( E^{ac} \), activation energy
- \( k_b \), Boltzmann constant
- \( T \), absolute temperature

Activation Energy of the trap level

\( E^{ac} = 1.318 \text{eV} \)
Summary

- Electrical ($I$-$V$) characteristics of scCVDD detector are analyzed
- The dominant dark current conductivity of scCVDD detector is SCLC
- The activation energy level of the trap is 0.37~0.39eV
- After coating scCVDD with DLC the conductivity remains the same, i.e, SCLC and the activation energy is $(0.38 \pm 0.017)$eV at negative bias while at positive bias $E^{ac}=0.44$~0.54eV
- The DoI show SCLC mechanism with an activation energy of $E^{ac}=1.32$~1.026eV
Thank you for your attention