Analysis of Chemical-Vapor–Deposition Diamonds for Neutron Detection on OMEGA

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Summary

The energy deposited per incident neutron in a chemical-vapor–deposition (CVD) diamond detector was quantified

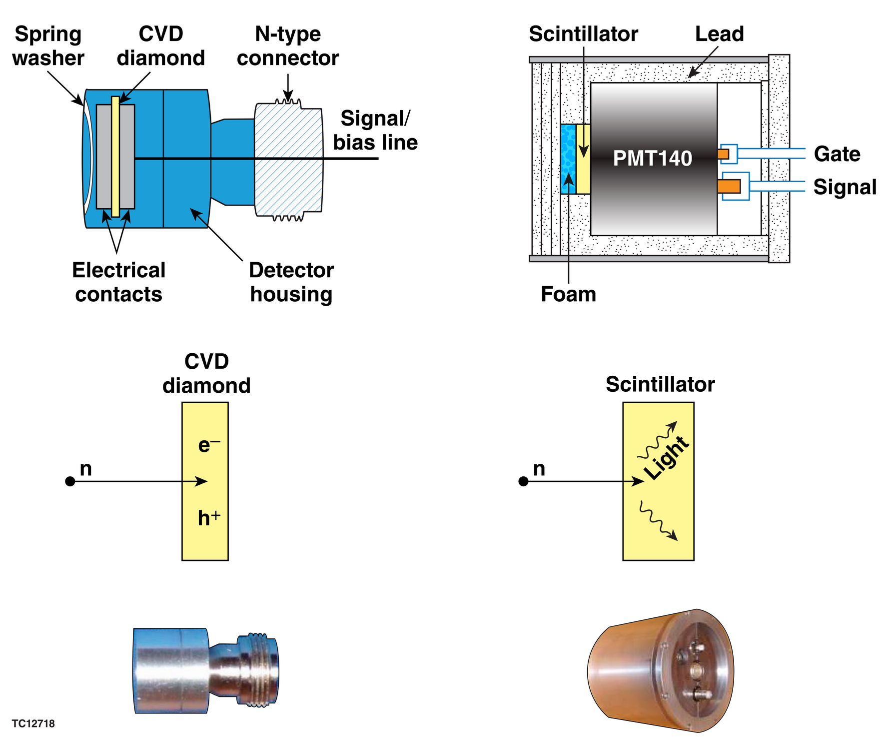
- A detection model for neutrons was developed using measured sensitivities
- Up to 44 keV is deposited per 14-MeV neutron interaction and 4.8 keV is deposited for 2.5-MeV neutrons
- The measured signal rise time was used to calculate the effective thickness of the detectors

TC12717

Motivation

CVD diamond detectors offer significant advantages over scintillators

CVD diamond detector		Scintillator
• Low noise because of wide band gap (5.5 eV) • Fast time response	Advantages	• Well-developed technology • Extensive response models exist
• Manufacturing variability • Response models needed • Less sensitive to low-energy neutrons	Disadvantages	• Response properties change over time • Decay times compromise time response



TC12718

Abstract

CVD diamond detectors are being investigated as alternatives to scintillators. A neutron-detection model has been developed to quantify the energy deposited per neutron interaction using measured detector sensitivities. The average energy deposited per interaction was 27 to 44 keV for 14-MeV neutrons and 4.8 keV for 2.5-MeV neutrons. Data were obtained for four detectors used on OMEGA. Using known electron mobility and signal rise times, the effective thicknesses of the detectors were calculated. This work provides insight that will aid the development of future CVD detectors.

TC12719

Incident neutrons react in CVD diamond through multiple reaction channels, creating electron-hole pairs and leading to a signal voltage as a function of time

Reaction*	Threshold (MeV)
$^{12}C(n, \gamma)^{13}C$	0
$^{12}C(n, \alpha)^{9}Be$	6.18
$^{12}C(n, n'2\alpha)^{4}He$	7.88
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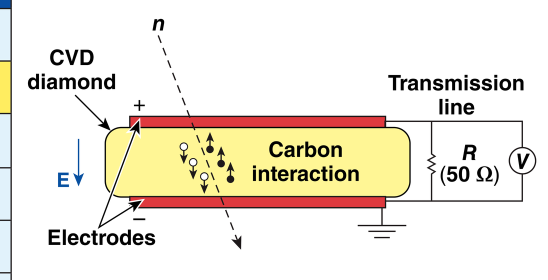


TC12720

*M. Angelone *et al*., Radiat. Meas. 46, 1686 (2011).

A model has been developed to estimate the energy deposited per neutron in a CVD detector

- The number of interactions within the detector is

$$\boxed{N_{int} = N_{inc}\,\sigma t\, n_C},$$

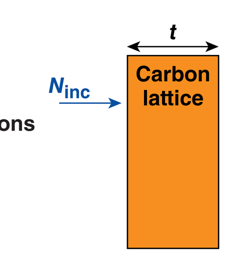
where

N_{inc} = number of incident neutrons = Yield • $\frac{\Omega_{det}}{4\pi}$

σ = total cross section for neutron–carbon interactions

n_C = number density of carbon atoms

Ω_{det} = detector solid angle

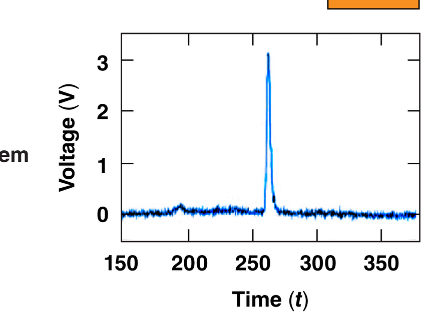


- The number of electron-hole pairs is determined from the experimental voltage pulse

$$\boxed{N_{eh} = \frac{\int Vdt}{2eR}},$$

where e = electron charge

R = resistance of detection system



- The average energy deposited per neutron interaction is

$$\boxed{E_{dep} = E_o \frac{N_{eh}}{N_{int}}},$$

where E_o = energy needed to create an electron-hole pair in diamond (= 13.2 eV)

- The detector sensitivity (α, neutrons/V • ns) is also determined from the experimental voltage pulse

$$\boxed{\alpha = \frac{N_{inc}}{\int Vdt}},$$

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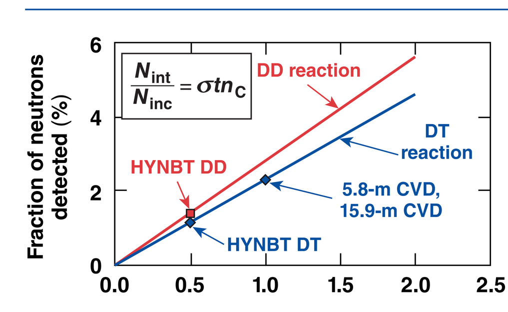
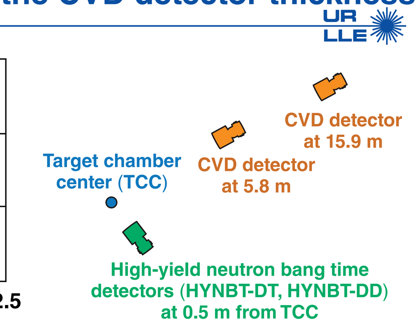
The fraction of incident neutrons detected is determined by the total cross section and the CVD detector thickness





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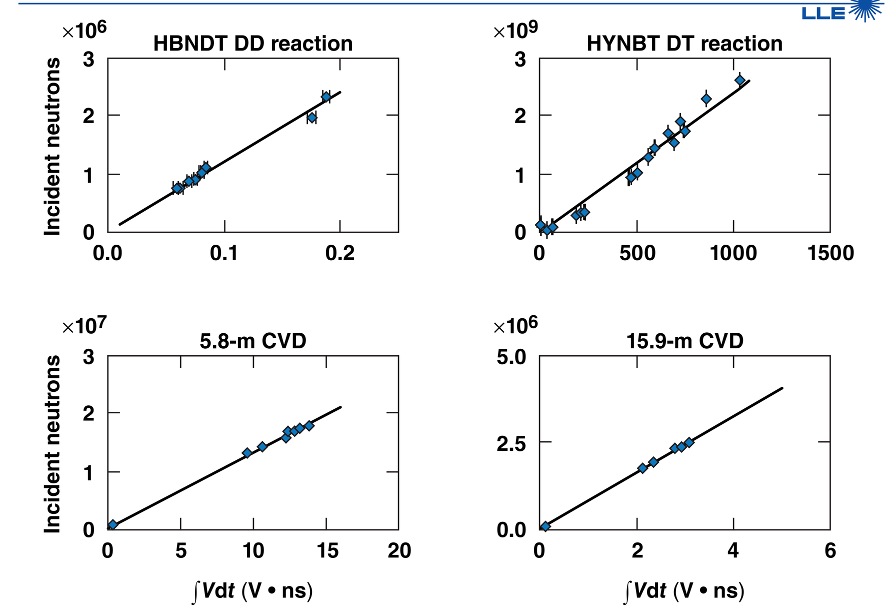
Different sensitivities are observed for different CVD detector systems



- The variability is dependent on factors related to the fabrication of synthetic diamond
  - mosaic structure
  - dopants, both intended and unintended
  - dopant concentration
  - microcrystalline size

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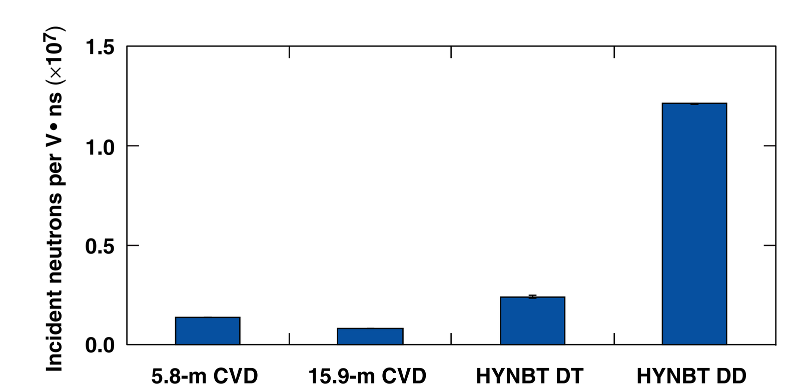
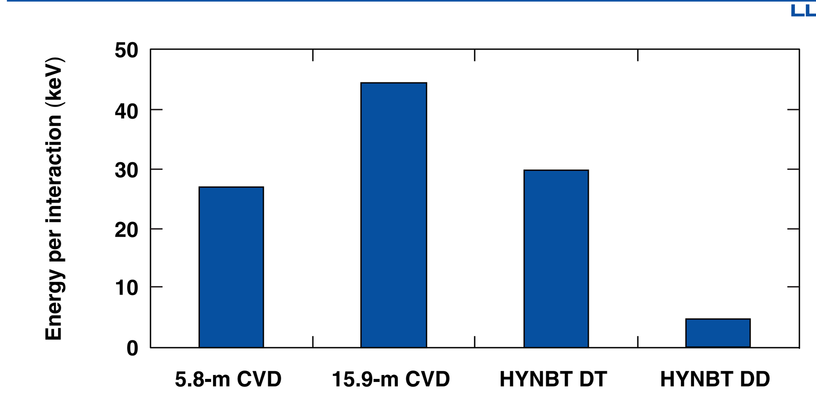
The model uses the measured sensitivities



TC12724

The average energy deposited per neutron interaction has been calculated for different CVD diamond detectors



TC12725

A model was used to calculate the effective thickness of each detector

- The effective thickness is given by*

$$\boxed{L_{eff} = \tau * \mu * \frac{V}{L}},$$

where

τ = rise time (10% to 90%)

μ = electron mobility in diamond

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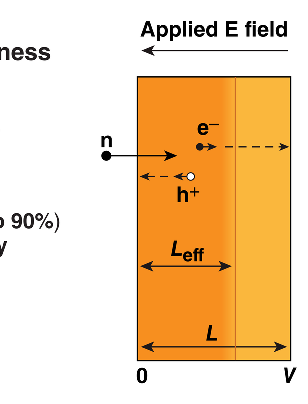
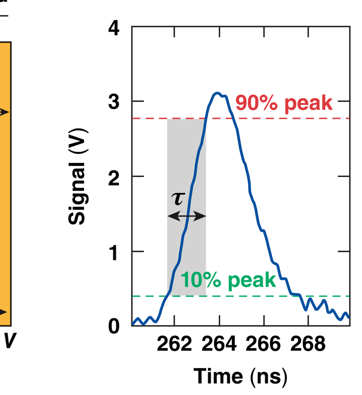
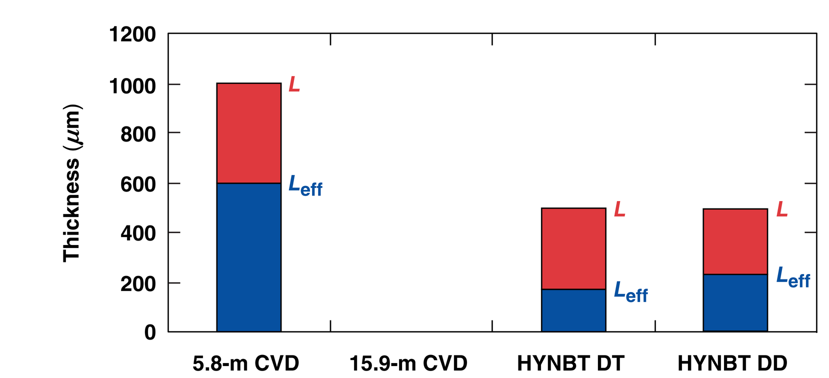




TC12726

*E. Pavlica and G. Bratina, Appl. Phys. Lett. 101, 093304 (2012).

The effective thickness is consistently less than the total thickness



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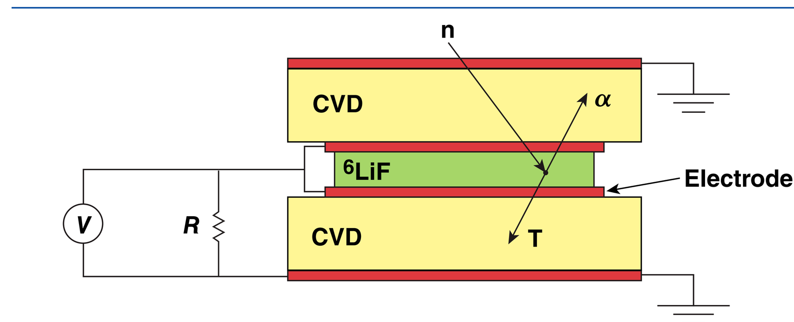
Future Developments

A layer of ^{6}LiF can be used to increase the sensitivity to low-energy neutrons



- Neutrons interact with ^{6}LiF in the 95% enriched ^{6}LiF layer

$$n + {}^{6}Li \longrightarrow T\,(2.73\ MeV) + \alpha(2.06\ MeV)$$

- The T and α are emitted at 180°, so either the T or the α is detected
- Neutrons below 6 MeV can be detected

TC12728

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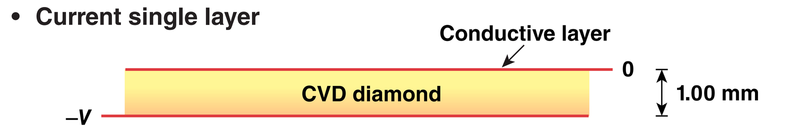
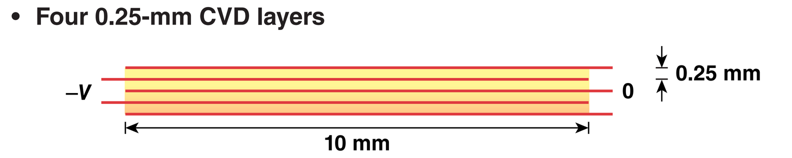
Multilayered structures can be used to improve the response for large neutron fluxes

- Current single layer



- Four 0.25-mm CVD layers



- Conductive layers are added to decrease the thickness of the electron-hole drift regions
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TC12729

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Scintillator

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Disadvantages

CVD diamond detector

- Manufacturing variability
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Scintillator

- Response properties change over time
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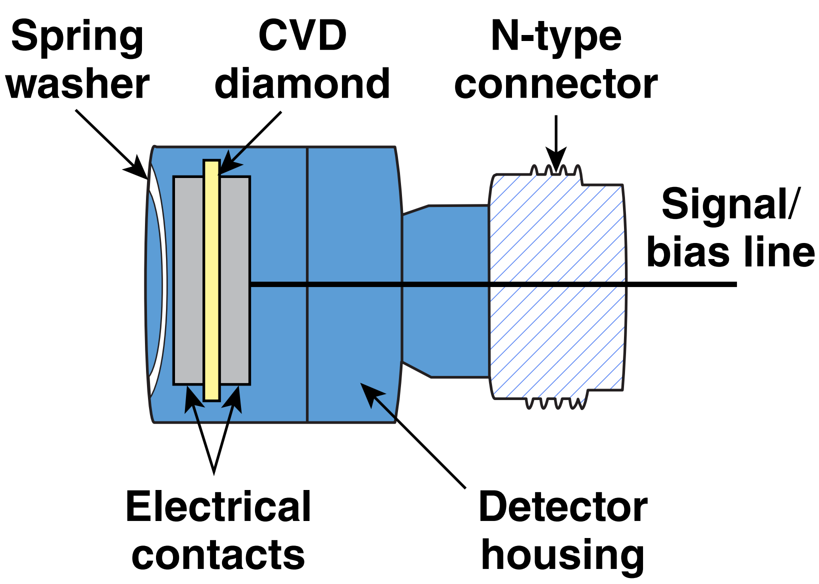

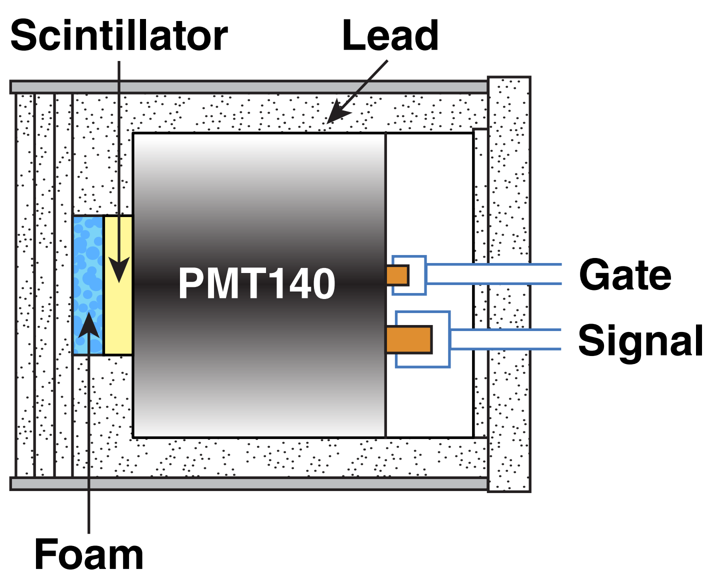

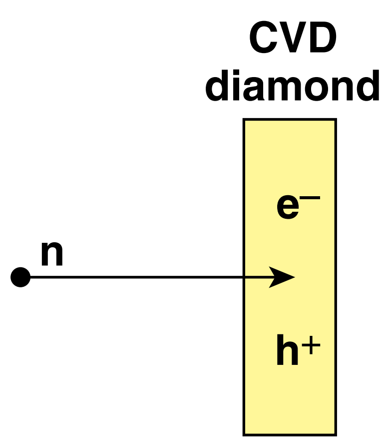

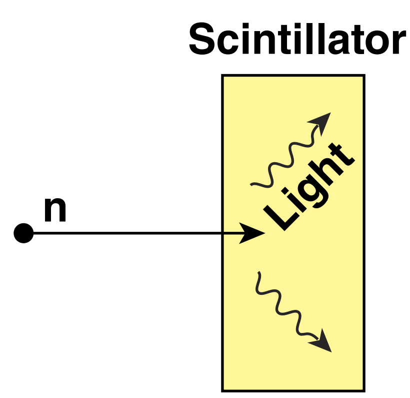

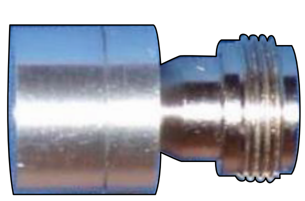

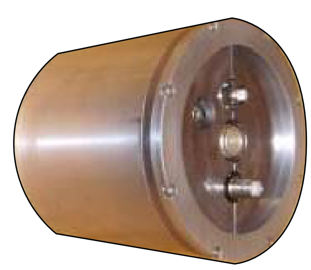

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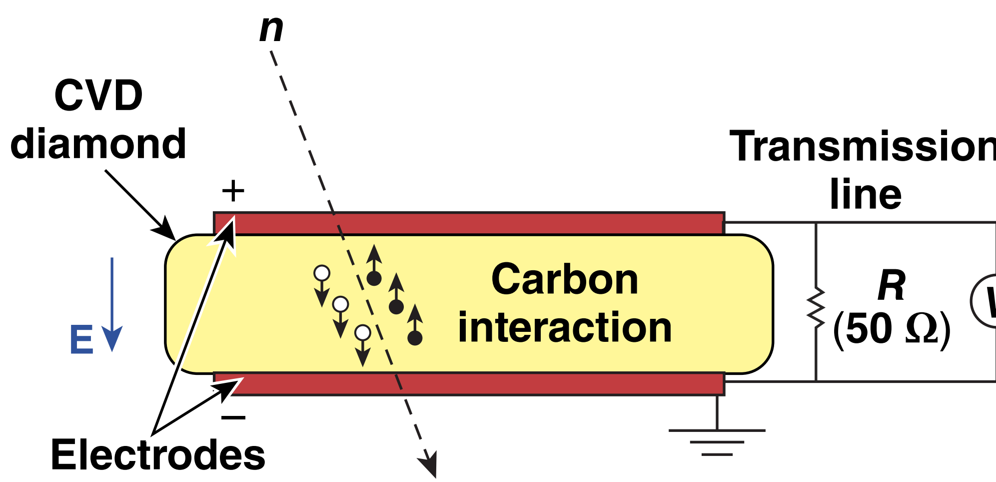

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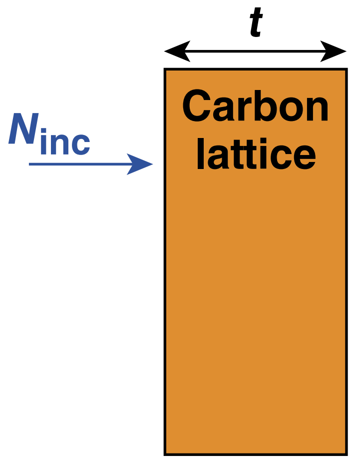

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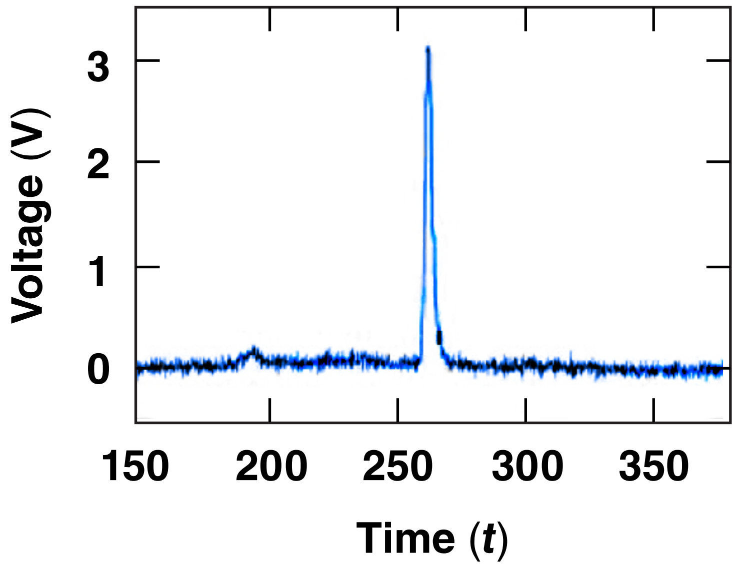

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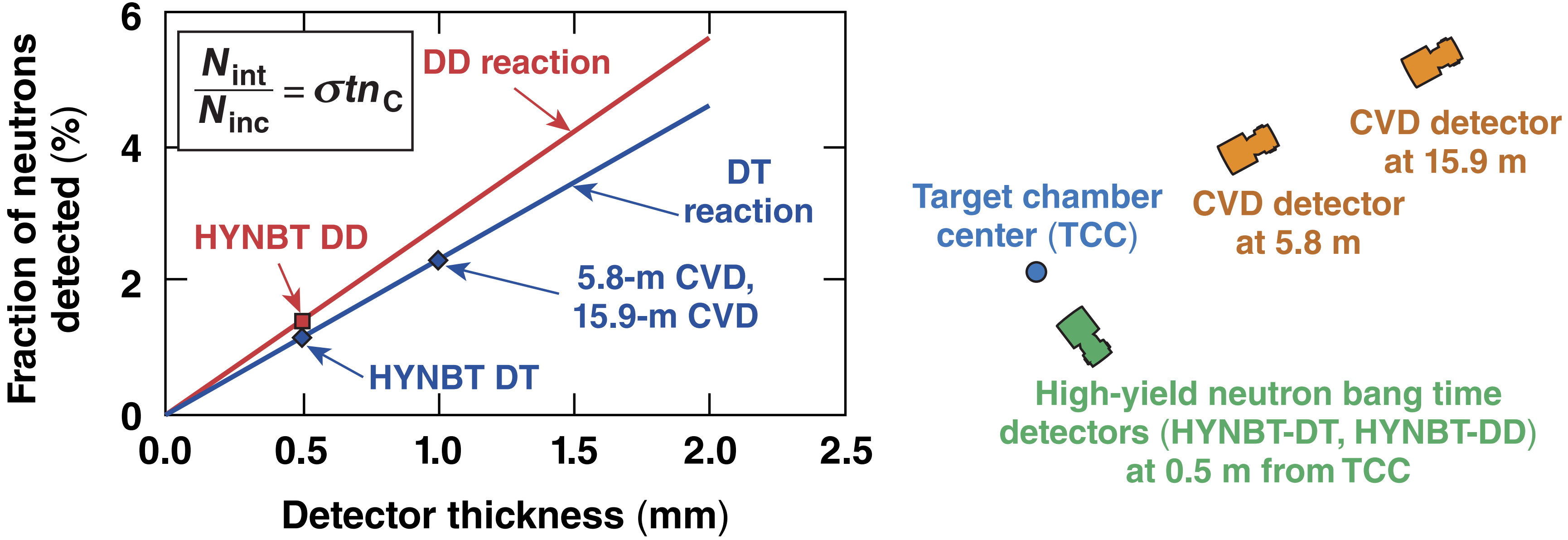

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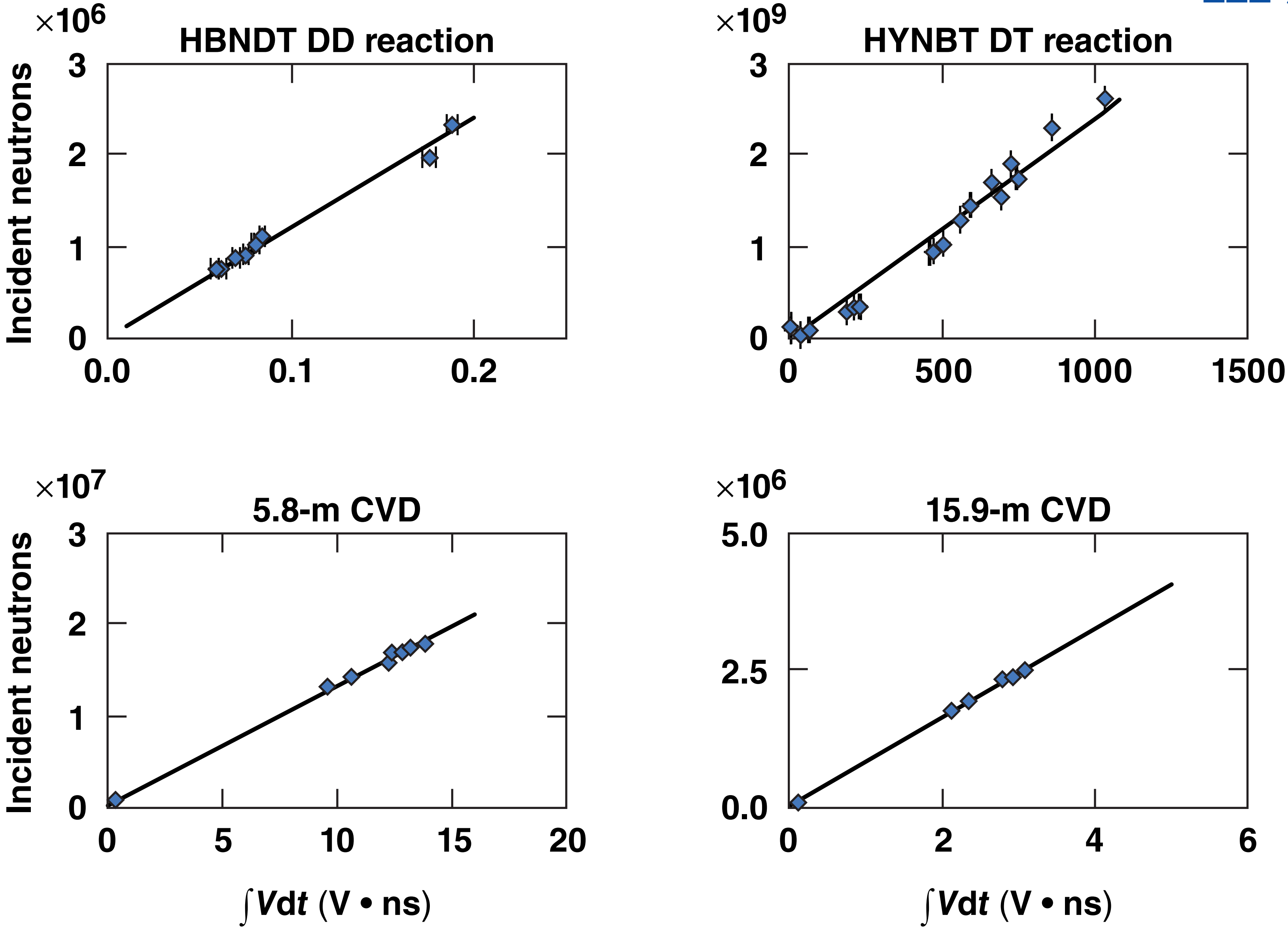

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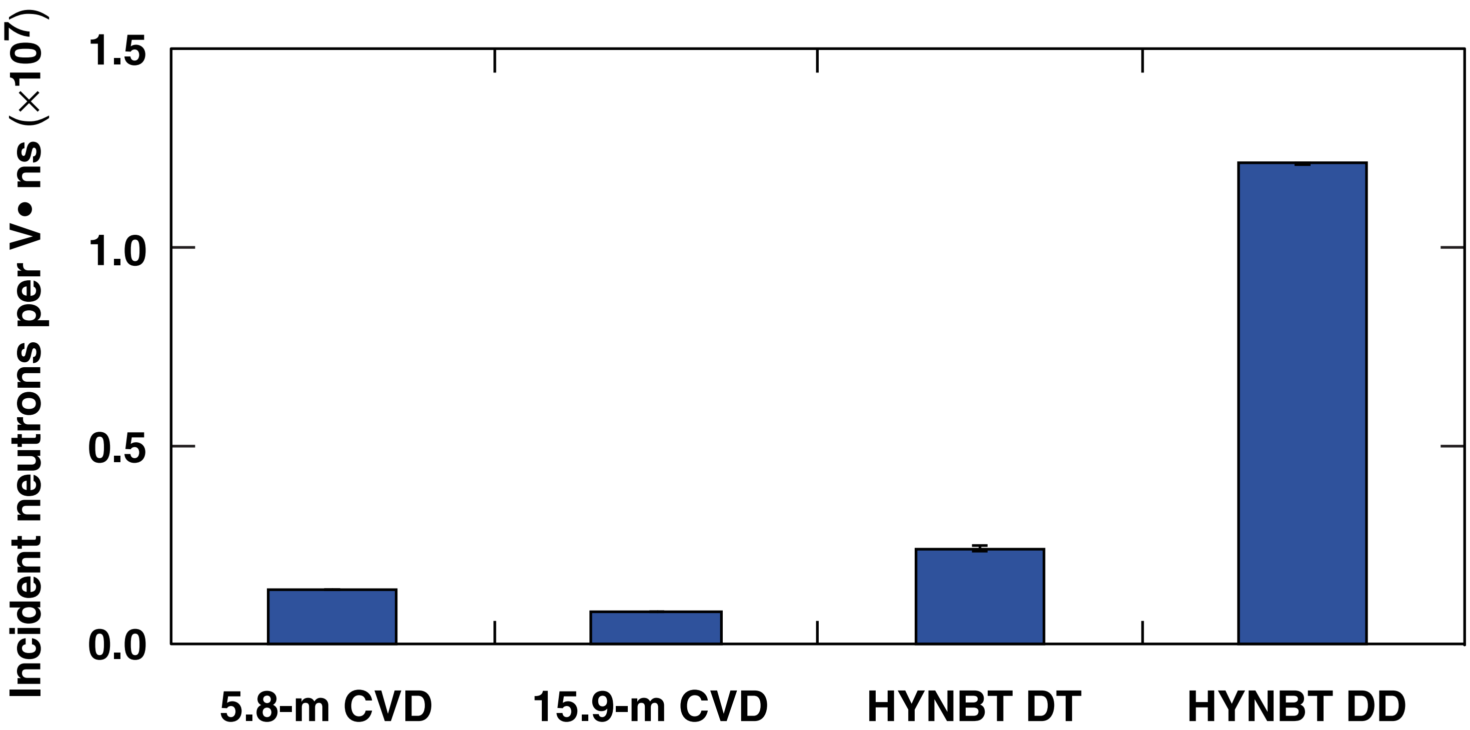

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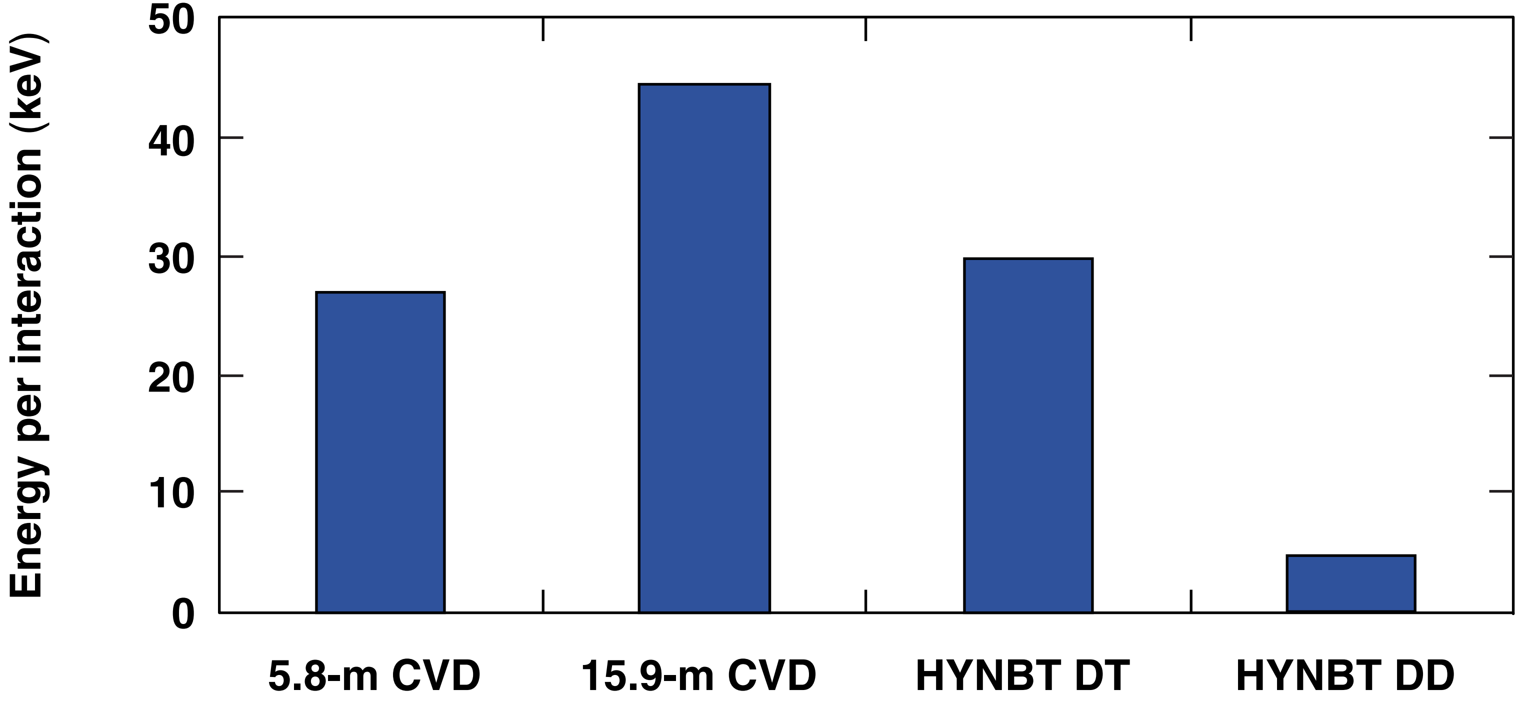

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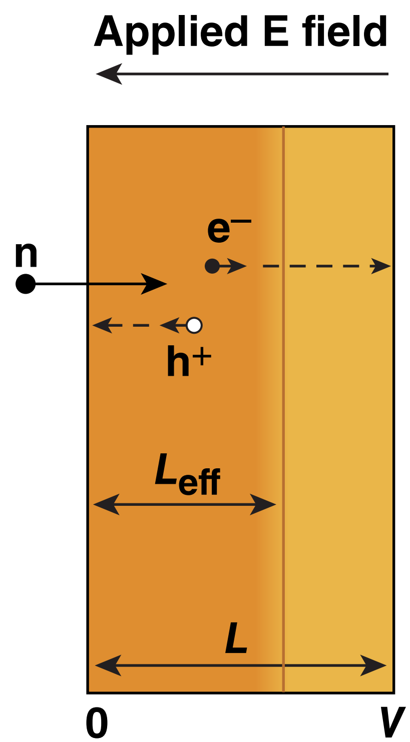

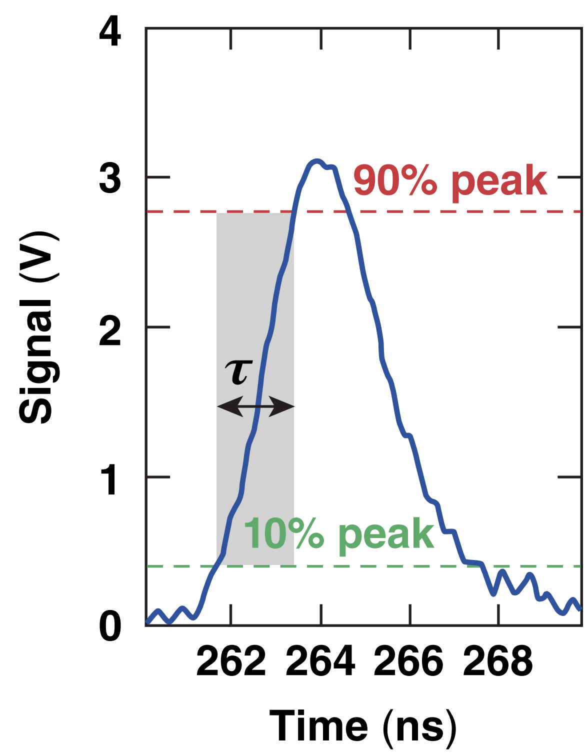

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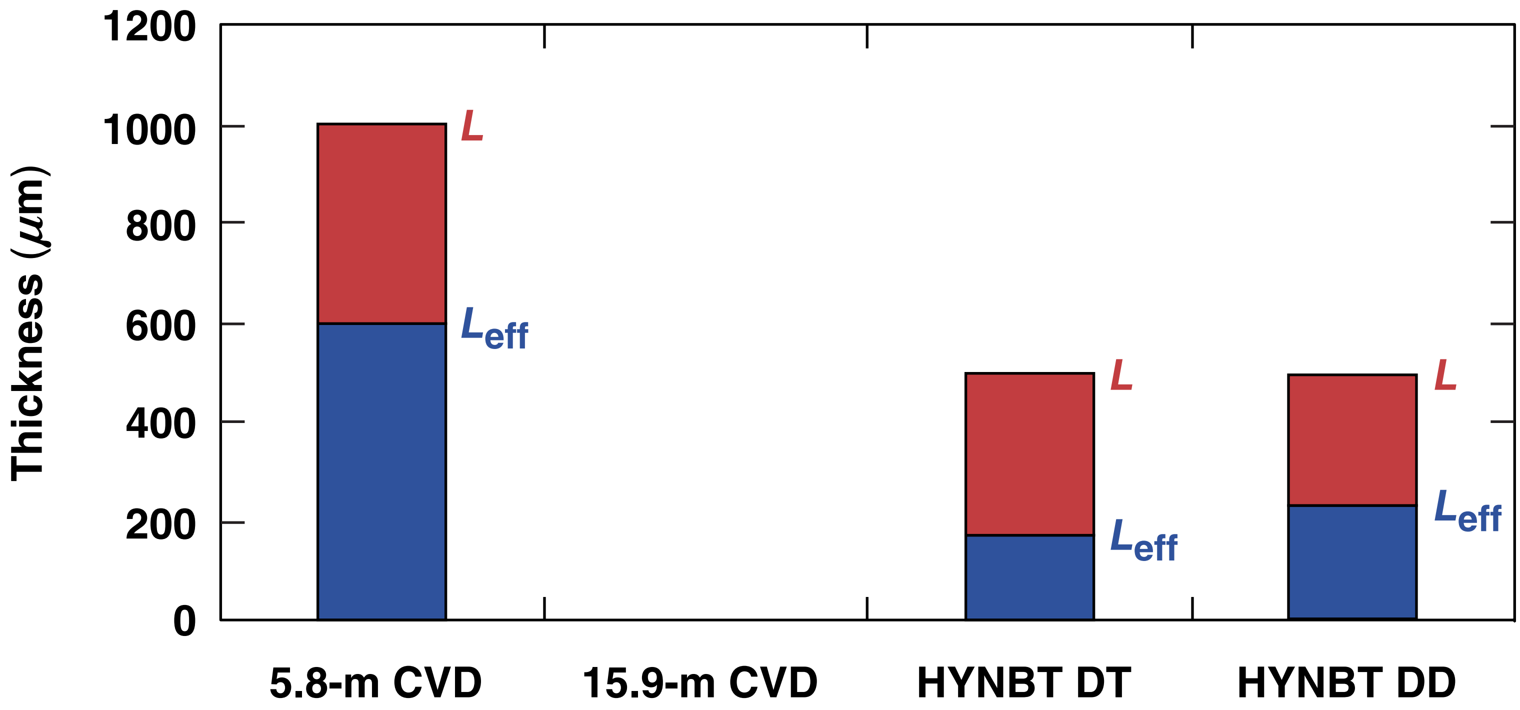

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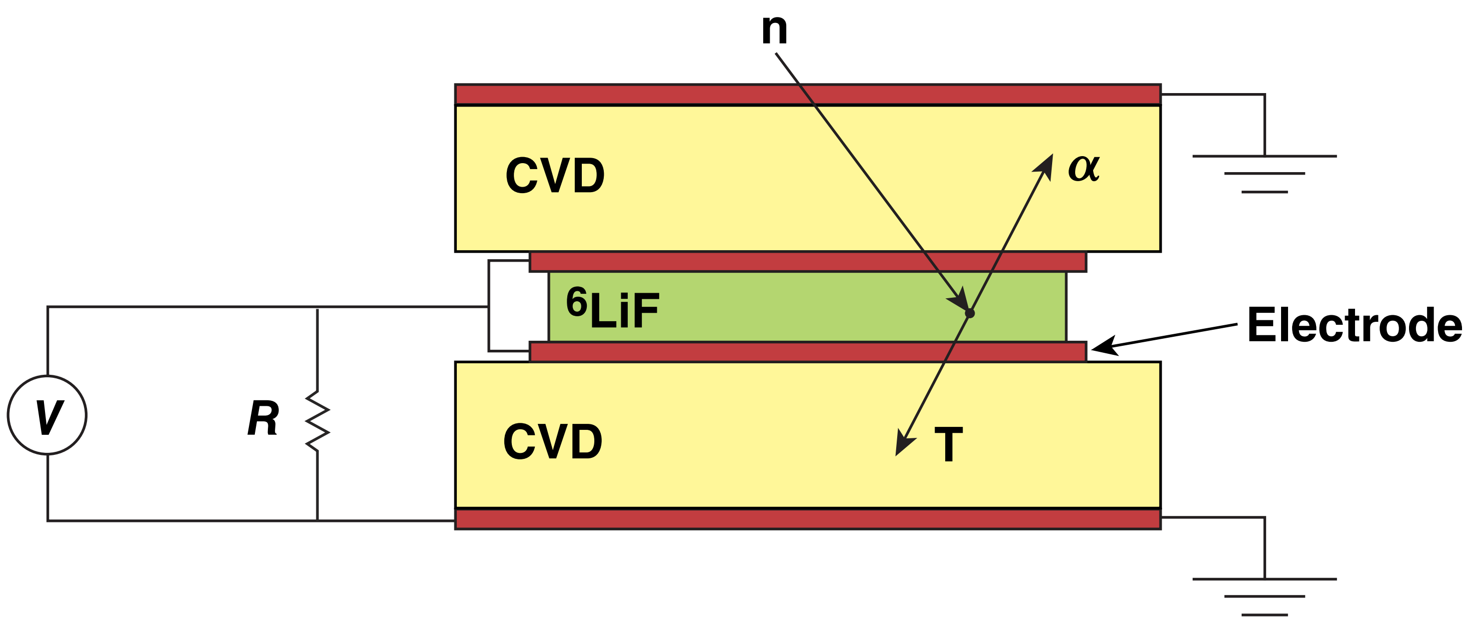

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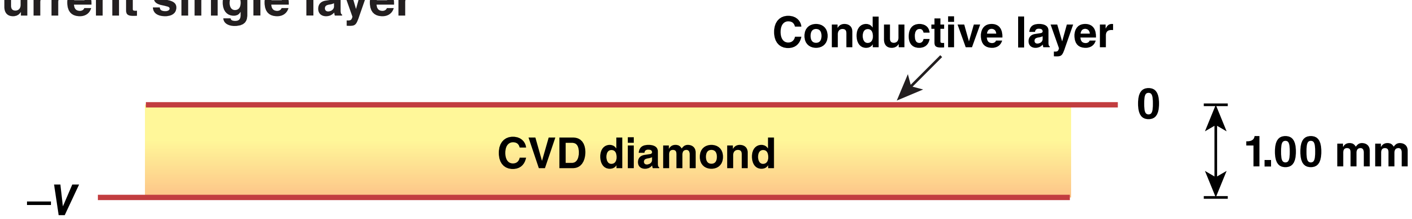

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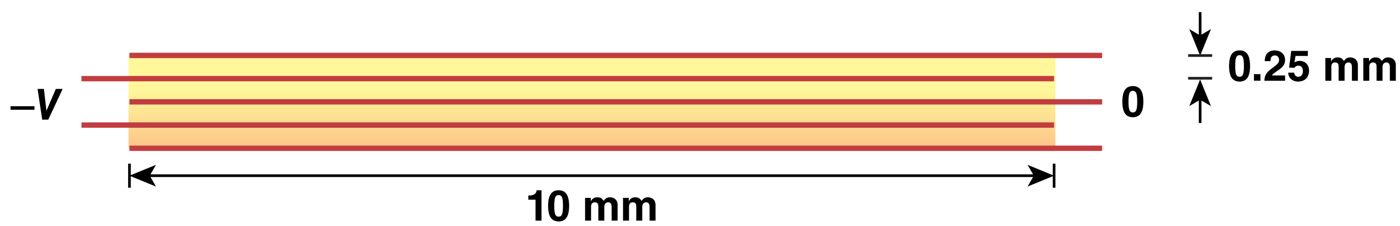

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