In-Core, Solid-State Flux Monitor

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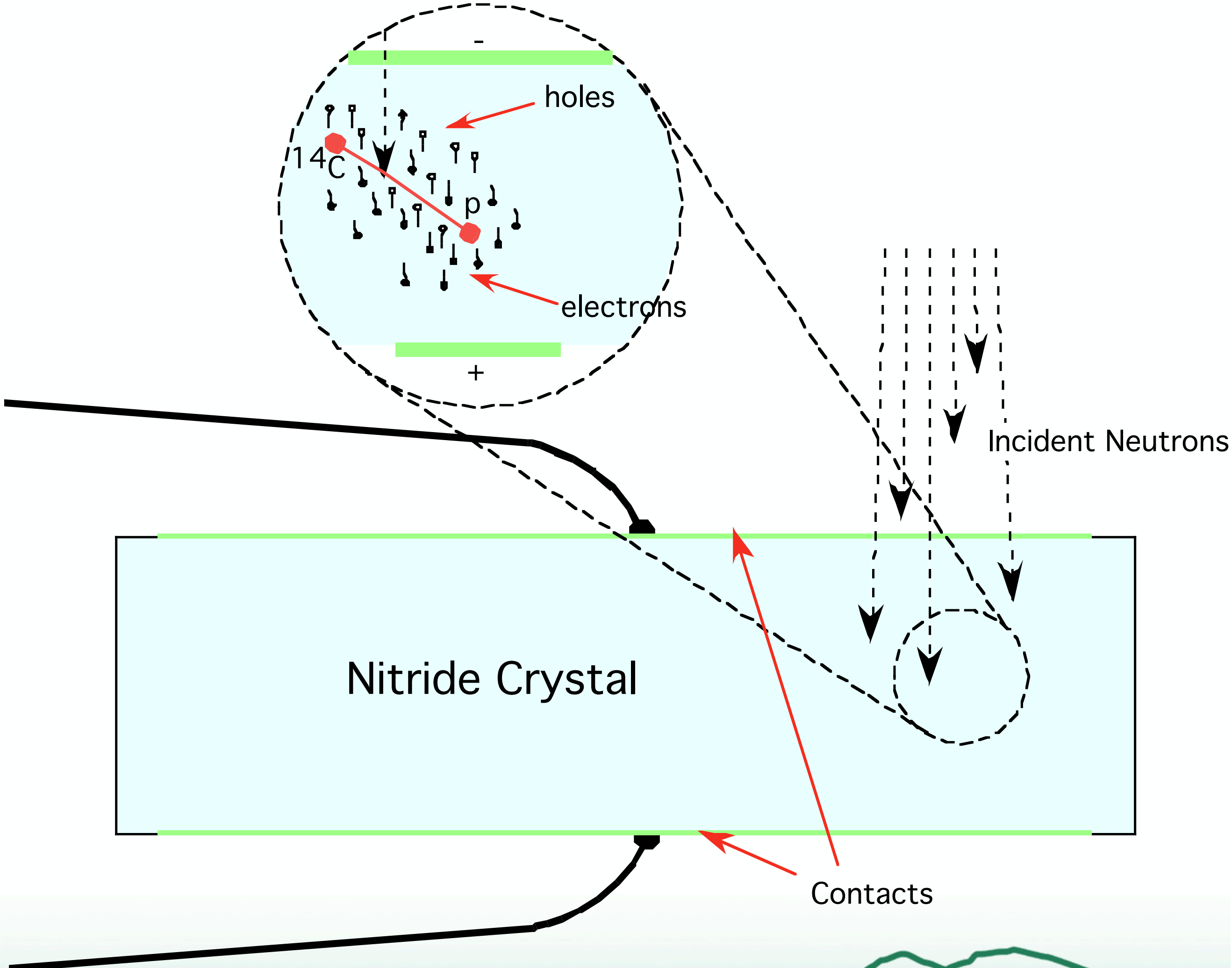
In-core Flux Measurement Technology has Significant Limitations

- Self powered neutron detectors are inherently slow, small-signal devices
- Fission chambers are large and tend to burn out rapidly
- Gas filled detectors require high integrity sealing which becomes more challenging as temperatures increase
- Solid-state form of detector has several advantages
  - Small (mm square)
  - Mechanically robust (no seals)
  - Temperature tolerant (wide band-gap solids)
  - Inexpensive
- Local flux peaking limiting operating factor
  - Fuel failure directly tied to local flux peaking
  - High accuracy flux map may allow tighter operating margins

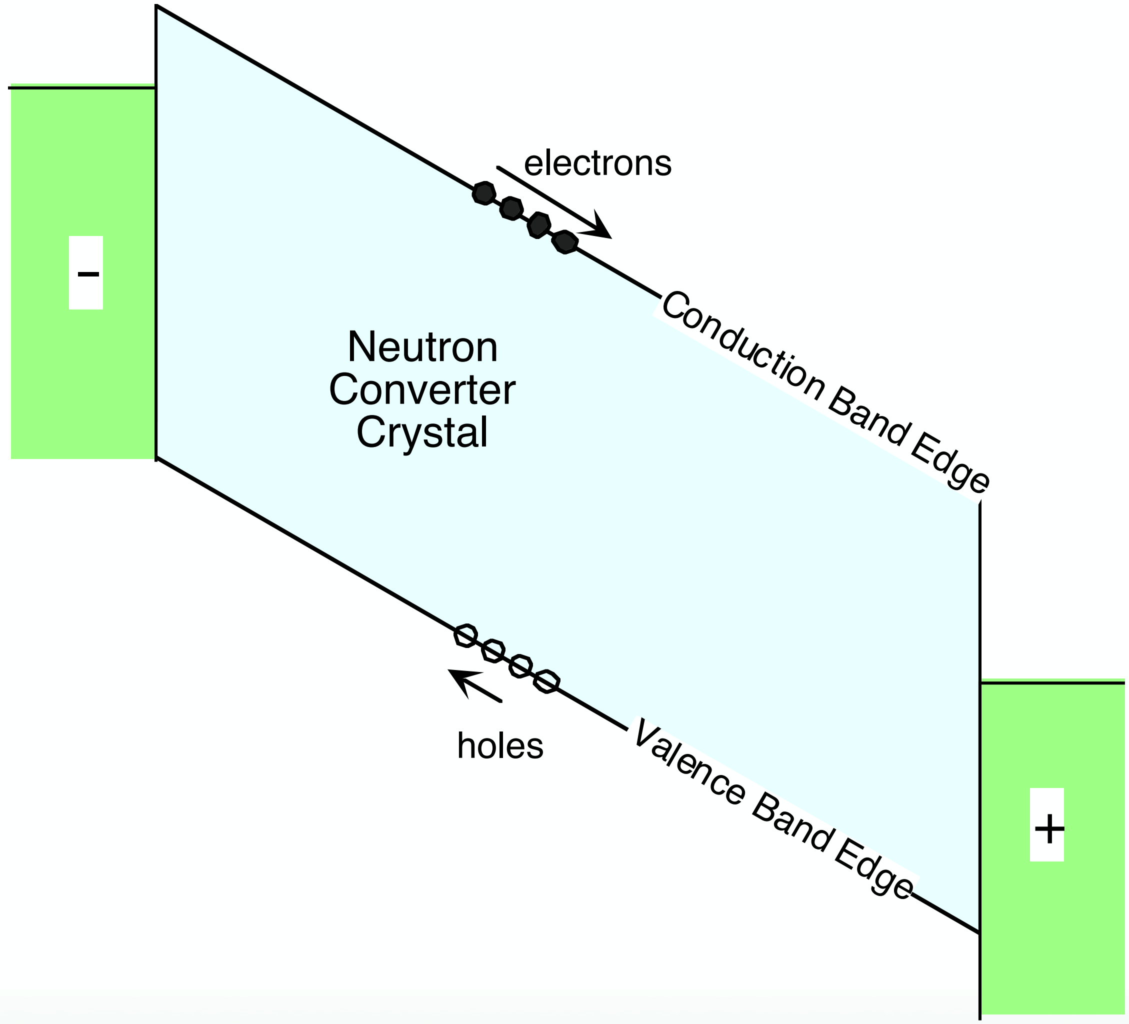
Solid-State, In-core Flux Monitor Functions as a Flux Sensitive Resistor

- **Wide band-gap crystal have very high resistances**
- **Radiation interaction produces free charge carriers**
- **Motion of free carriers under applied field is a current**
- **Magnitude of current is measure of flux**



Requirements for Proper Functioning

- **Neutrons produce dominant amount of charge carriers**
  - **Thermal and gamma induced carriers produce false response**
- **Carriers are free to move**
- **Applied field penetrates the crystal**
- **Neutron sensitivity invariant with fluence**



Group III Nitrides Have Advantageous Properties

- **High charge mobility**
  - **Good field penetration**
  - **High dielectric breakdown strength**
- **Wide band-gap**
  - **Insignificant thermal generation of carriers**
- **High electrical resistance > 10^{14} Ω-cm common**
- **High-temperature tolerance with very good chemical resistance**
- **High-mechanical robustness**
- **Reasonable fabrication route**
  - **Commercially available**

Key Environmental Variables

- 20 °C to 900 °C
- 10^4 to 10^{14} neutrons/(cm^2-s) startup to full power
- Gamma dose rate up to 10^6 Gy/hr

^{10}Boron-Nitride Background

$$^{10}B + ^{1}n \rightarrow \begin{cases} ^{7}Li + ^{2}\alpha & (6\%) \\ ^{7}Li + ^{2}\alpha + \gamma & 94\% \rightarrow \begin{bmatrix} E_{\gamma} = 480 keV \\ E_{Li} = 840 keV \\ E_{\alpha} = 1.47 MeV \end{bmatrix} \end{cases}$$

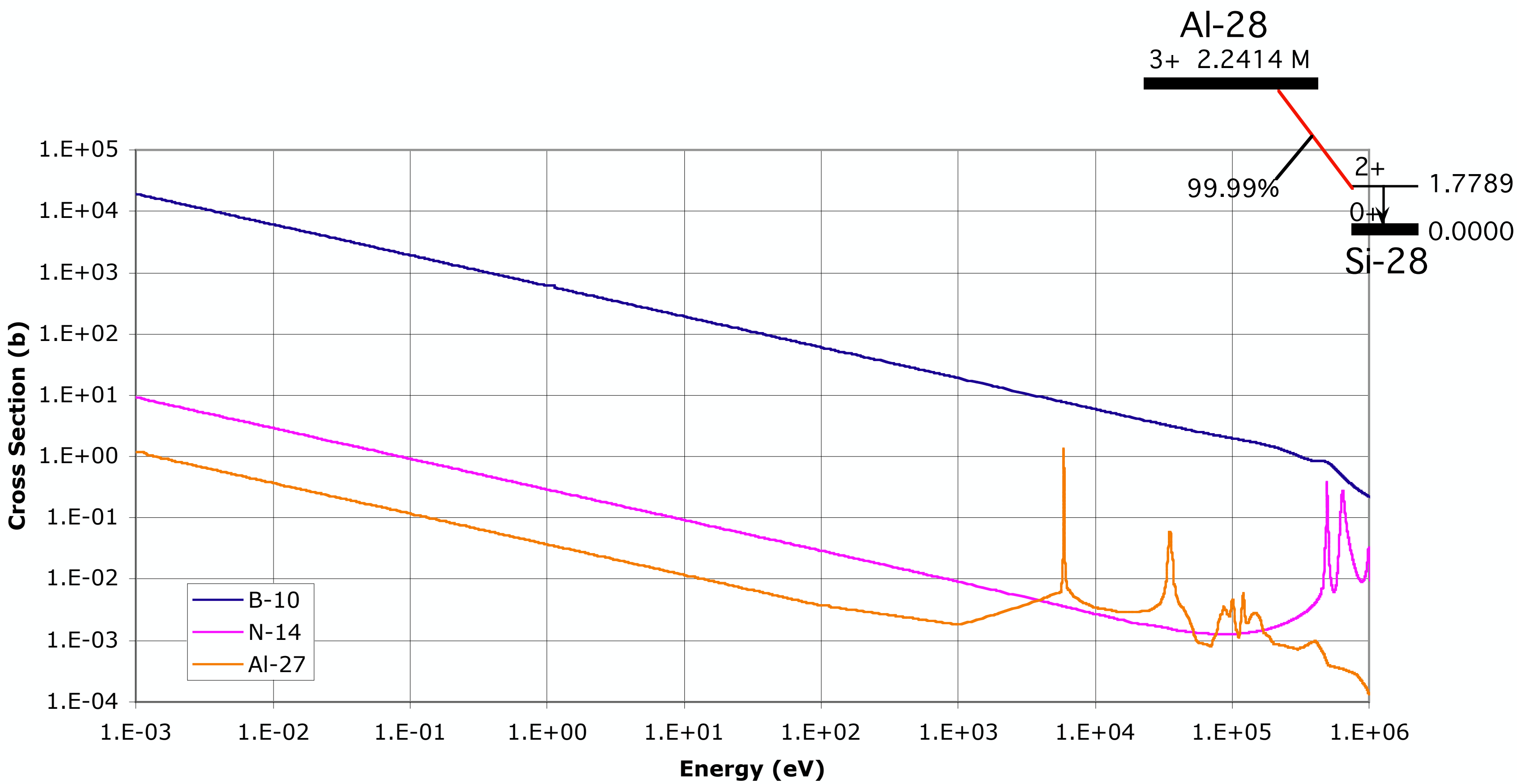
- **Two common material phases**
  - **Hexagonal**
    - **Soft, polycrystalline (white), CVD process, widely available in a variety of forms**
  - **Cubic**
    - **Very hard, only readily available in a few forms (grinding material)**
- **Long range charge carrier transport**
  - **Electron mobility roughly 500 cm^2/(V-s)**
- **Very high neutron blackness**
  - **Macroscopic thermal cross section ~125 [1/cm]**

Aluminum-^{14}Nitride Background

$$^{14}N + {}^{1}n \rightarrow {}^{14}C + {}^{1}p \quad \left\{ \begin{array}{l} E_C = 585\, keV \\ E_p = 42\, keV \end{array} \right\}$$

- **Single phase (hexagonal - wurtzite structure)**
- **Natural Nitrogen is 99.6%^{14}N - remainder ^{15}N**
- **Hardness comparable to quartz**
- **High thermal conductivity 175 W/(m-K)**
- **Electron mobility ~100 cm^{2}/(V-s)**
- **Lower neutron interaction probability**
  - **Macroscopic thermal cross section 0.087 [1/cm]**
- **Commercially available as polycrystalline solid (electronic substrate) - http://www.aluminumnitride.com**

$^{10}B(n,□)^{7}Li$, $^{14}N(n,p)^{14}C$, and $^{27}Al(n,abs)$ Cross Sections

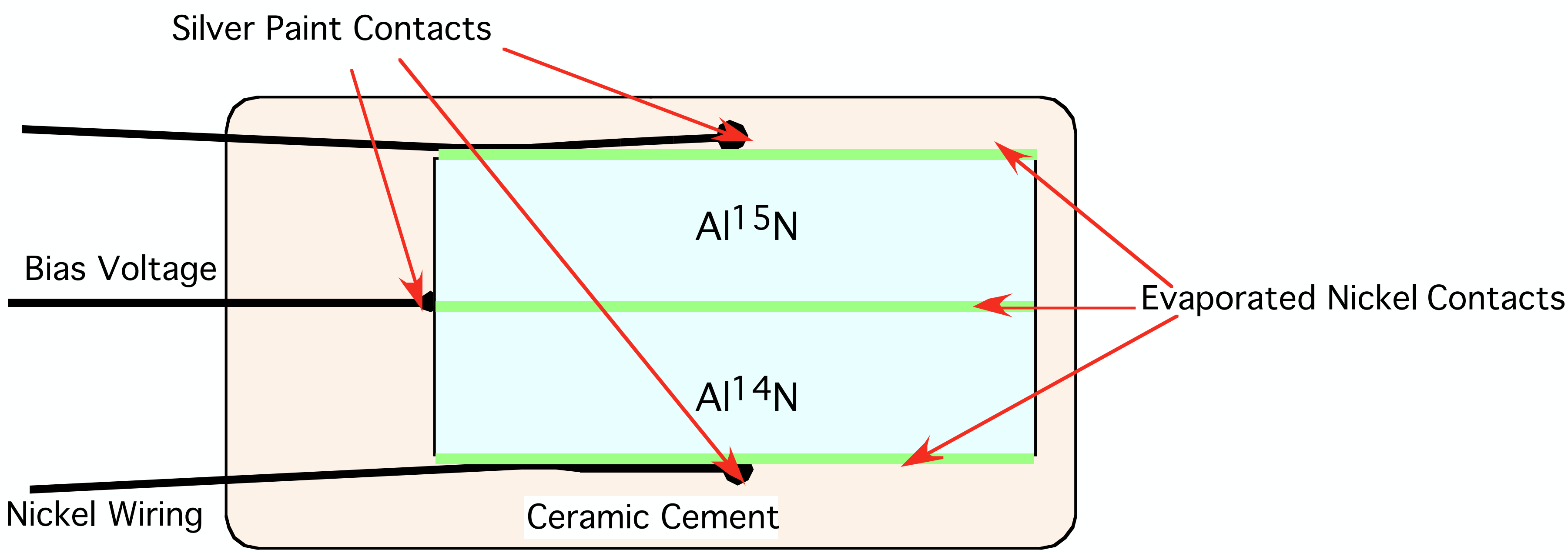


Hexagonal Boron Nitride vs. Aluminum Nitride

- Very high neutron blackness
- Q ~2.31 MeV
- Band gap 4.07 eV min, 4.2 eV direct
- Boron Number Density = 3.23e22 atoms/cm^3
- Interaction Rate (in 1e-12 m^3)
  - 1.2e10/s at power; 1.2/s at startup
- Daily burn-up at power ~0.969
- Heating rate at power 4.4 kW/cm^3

- Lower neutron blackness
- Q~627 keV
- Band gap 6.28 eV
- Nitrogen Number Density = 4.75e22 atoms/cm^3
- Interaction Rate
  - 8.7e6/s at power; 8.7e-4/s at startup
- Annual burn-up at power ~0.994
- Neutron to gamma dose at power ~1:1 (gamma dose rate ~10^6 Gy/hr)
- Must use in ^{15}N compensation channel for gamma correction

Current Fabrication Concept



Main Initial Research Thrusts

- What mechanical arrangement will survive thermal cycling?
- How can I obtain ^{15}N enriched AlN?
- What is the minimum detectable flux?
- How does the response change with fast fluence?
- How does the response change with dose?
- What is the optimum device thickness?