Studies on 3D Fusion Reactions in Titanium Deuteride under Ion Beam Implantation

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D-Beam Enhances 3D-Fusion if CF DD Fusion is Stimulated

- Without Stimulation results in 2D fusion

With Stimulation enhances 3D Fusion Rate

Lattice Trapping Potential
Aim: To Seek 3D Fusion in Solid Titanium Octahedral Site Deuteron at Tetrahedral Site

Using low energy ion beams, products of 3D fusion are detected.

Beyond the range of incident beam, active zone will be formed by Electron phonon interaction in metal-deuteride.

In Active zone, transient D-cluster with electron quasi-particles will induce very enhanced 3D and 4D multi-body fusion reactions.
~Multibody Fusion in Condensed Matter~

**Key Point**

- High D-absorption ($\text{TiD}_x \sim 1.8$)
- Regular lattice structure (out of beam stopping range)
- Screening effect by presumed electronic quasi-particle

**Possible Branches**

\[
\text{D+D+D} \rightarrow ^6\text{Li} \rightarrow t(4.75\text{MeV}) + ^3\text{He}(4.75\text{MeV}) \quad \text{...(a)}
\]
\[
\rightarrow d(15.9\text{MeV}) + ^4\text{He}(7.93\text{MeV}) \quad \text{...(b)}
\]
\[
\rightarrow n + p + ^4\text{He} + 20.1\text{MeV}
\]
Experimental Chamber and Measuring System

- TiDx (x>1.7) was cooled with Peltier device.
- E & delta-E counter telescope type charged particle detector was used for Particle Identification.
- Ek detector was used for measuring total kinetic energy of particles.
Estimation of Particle-Energy-Losses by TRIM Code

- D + D → p + t + 4.02 MeV
- 3He + n → 3.25MeV
- 3D → t + 3He + 9.5 MeV
**Branch (a)** $\text{D}+\text{D} \rightarrow t(4.75\text{MeV})+^{3}\text{He}(4.75\text{MeV})$

- **Pre-Amp.**
- **L.Amp.**
- **M.C.A.**

- **Aperture** 7mm
- **TiD$_4$**
- **SSHD**
- **Absorbing foil** Al 3µm

- **300 keV deuteron beam**

**Spectrum A**
- $^{12}\text{C}(d,p)^{13}\text{C}$
- $^{14}\text{N}(d,\alpha)^{12}\text{C}$

**Spectrum B**
- D-D proton
- D-D proton double pile up

- **Current Integrator**

**Pile-up reduction technique**

**E-$\Delta E$ Counter Telescope**

**Spectrum A**

**Spectrum B**
(a) $D+D \rightarrow t(4.75\text{MeV}) + ^3\text{He}(4.75\text{MeV})$

- $D$-$D$ proton ($\Delta p=0.55\text{MeV}$)
- $D$-$D$ triton ($\Delta =0.7\text{MeV}$)

E-detecto

Counts/channel

Energy (MeV)

$D$-$D$ proton ($2.4\text{MeV}$)

No "sholder"

$D$-$D$ proton pileup

$3D$ triton?

$[^3\text{He} \text{by } 3D]/[\text{p by } 2D] = 1.1\times10^{-4}$

$[t \text{ by } 3D]/[\text{p by } 2D] = 1.2\times10^{-4}$

$[3D]/[2D] = 1.15\times10^{-4}$
Spectra by delta-E Detector; TiDx Sample

- Data are taken for 50, 70, 100, 150, 200 and 300 keV of D-beam energy
- Peak around 3.5 MeV may correspond to $^3$He by 3D fusion
- To this evaluation, integral counts in h3-dash window were used
Yields by h3-dash ([3D]) vs. 2D Yields and Impurity Reaction

- Energy Dependence of h3-dash yields show much slower decrease than that of possible impurity reactions.
- Data for h3-dash were reproduced for 4 times.
• [3D]/[2D] Yield Ratios by Experiment are in the order of 1E-4 to 1E-3.
• Increasing trend in lower energy region than 100 keV may result in indirect 3D reactions.
• Theoretical values by the conventional Random Nuclear Reaction Theory has given [3D]/[2D] ratio to be in the order of 1E-30.
• Experiment shows 1E+26 anomalous enhancement.
(b) $\text{D+D+D} \rightarrow \text{d(15.9MeV)} + \text{^4He(7.93MeV)}$

500$\mu$m did not stop unknown signals which should have high energy.

3D Fusion emits 15.9 deuterons.

Particle identification by $E-\Delta E$ Counter Telescope.
(b) $^3D + ^3D \rightarrow ^3d(15.9\text{MeV}) + ^4\text{He}(7.93\text{MeV})$

Home-made $\Delta E - E$ was mounted to make counter telescope with $15.9\text{ MeV}$ deuteron emission, $\Delta E$ detector takes $1.5\text{ MeV}$ and $E$-det $3.2\text{ MeV}$.

Titanium deuteride (TiD) energy loss $10.9\text{ MeV}$, $\Delta E = 1.5\text{ MeV}$, $E = 3.2\text{ MeV}$. Absorbing foil Ti: 500$\mu$m, $\Delta E$ detector Si: 66.5$\mu$m, E-detector Si: 200$\mu$m.
Two dimensional charged particle spectrum measured by E-ΔE counter telescope
Branch (b) $D+D \rightarrow d(15.9\text{MeV}) + ^4\text{He}(7.93\text{MeV})$

Measured energies are considerably scattered.

Ti500 $\mu m$ filter makes considerable energy struggling.

TRIM calculation gave simulation

Energy struggling from 4.5 to 6 MeV was estimated by TRIM

Measured particles can be 15.9 MeV deuterons from 3D fusion reaction
Branch (b) D+D+D $\rightarrow$ d(15.9MeV) + $^4$He(7.93MeV)

Random 3D Fusion Yield $\sim 7.8 \times 10^{-30}$
D-D fusion Yield

[D-D proton yield]
D+D $\rightarrow$ p+t+4.0MeV (50%)

[3D deuteron yield]
$\sim 4.4 \times 10^{-4}$

[D-D fusion Yield]

$\sim 2.2 \times 10^{-4}$

* 3D $\rightarrow$ d(15.9MeV) + $^4$He(7.93MeV) yield was $10^{25}$ times enhanced.

* 3D multibody fusion has roughly 1:1 branching ratio for
branch (a) $^3$He(4.75MeV) + t(4.75MeV)
branch (b) d(15.9MeV) + $^4$He(7.93MeV)
Experiment with Si beam

**Merits**

* Si beam can be used only for excitation.
  We can discuss about whether multi-body fusion reaction contains only direct
  Beam effect or with *indirect 3D fusion reactions which is true CF phenomenon.*

* No impurity reactions → easy to detect aimed signals

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2D fusion reactions by knocked-on cascade
Will be detected and what?
In 3 MeV~4 MeV region, we detected some signals which suggests unusual reactions.

\[ \text{Si beam Irradiation Experiment} \]

Graph showing counts per channel vs. energy in MeV.

\[ 3D \to ^3\text{He}(4.75\text{MeV}) + t(4.75\text{MeV}) \]

Which suggests unusual reactions.
Prediction for Si beam Experiment

3D $\rightarrow$ $^3$He(4.75MeV)+t(4.75MeV) makes What energy deposits?

Beam range $\sim$ 1.7µm

Active Zone is assumed as 1.7 µm

<table>
<thead>
<tr>
<th>Charged particle</th>
<th>Estimated Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td>4.5</td>
</tr>
<tr>
<td>$^3$He</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Detected unusual signals may be these triton and $^3$He by 3D fusion.

However, due to poor statistics, we need further study to conclude.
### Conclusions

<table>
<thead>
<tr>
<th>Reaction Branch</th>
<th>Beam</th>
<th>Method</th>
<th>Result</th>
<th>Ratio to D-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 3D→ ( ^3\text{He}(4.75\text{MeV})+t(4.75\text{MeV}) )</td>
<td>Deuteron</td>
<td>E-ΔE counter telescope</td>
<td>( ^3\text{He} )</td>
<td>( 2.2 \times 10^{-4} )</td>
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<tr>
<td></td>
<td></td>
<td>Pile-up Reduction</td>
<td>( t )</td>
<td>( 2.0 \times 10^{-4} )</td>
</tr>
<tr>
<td></td>
<td>Silicon</td>
<td>SSBD</td>
<td>3D ?</td>
<td></td>
</tr>
<tr>
<td>(b) 3D→ ( \text{D}(15.9\text{MeV})+^4\text{He}(7.9\text{MeV}) )</td>
<td>Deuteron</td>
<td>E-ΔE counter telescope</td>
<td>( d )</td>
<td>( 4.4 \times 10^{-4} )</td>
</tr>
<tr>
<td>HDD→ ( \text{P}(19.1\text{MeV})+^4\text{He}(4.75\text{MeV}) )</td>
<td>Proton</td>
<td>With various Absorption foils</td>
<td>( p )</td>
<td></td>
</tr>
</tbody>
</table>

* E-ΔE measurements gave detection of \( t, ^3\text{He} \) and high energy \( d \).  
3D fusion branching (a) and (b) \( \rightarrow 1 : 1 \)
Conclusions-2

- Experimental [3D]/[2D] yield ratios were in the order of $1E^{-3}$ to $1E^{-4}$, compared with $1E^{-30}$ by random nuclear reaction theory.

- Anomalous enhancement ratio of $1E^{26}$ suggests that electron screening effect on d-d Coulomb repulsion in TiDx lattice dynamics is far greater than that of Thomas-Fermi gas model.

- EQPET (Transient Electronic Quasi-Particle Expansion Theory) model can basically explain the unusual enhancement of screening effect.