**An Ignition Torch Based on Photoignition of Carbon Nanotubes at Elevated Pressure**

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**Abstract:**
Viewgraph/Briefing Charts

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An Ignition Torch Based on Photoignition of Carbon Nanotubes at Elevated Pressure

(patent pending)

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Background

• The source of high pressure in most combustion devices is the combustion
  – Ignition occurs at low pressure

• A research project at AFRL required ignition to occur while already at high pressure
  – Conventional spark ignition is unreliable at high pressure
  – Alternatives such as laser ignition were impractical

• The solution was a Photoignition Torch (PITCH)
  – PITCH is also electromagnetically quiet, and doesn’t interfere with instrumentation like spark ignitors do.
Photoignition of Nanostructured Solid Fuels by a Camera Flash

The photoignition torch (PITCH) uses a Xe-flash to create a spray of burning particles for initiation of combustions by utilizing ignition properties of carbon nanotubes (CNT).

**Top:** The complete hardware of a self-contained PITCH. The ignition capsule contains ~50 mg of solid fuel mixture of CNT and solid rocket propellants. PITCH is based on proven technologies that have been in use for decades in rocket industry.

**Right:** Photoignition of an encapsulated solid fuel mixture moments after the camera flash fires.
Photoignition Torch for Fast, Robust, and Scalable Ignition

TOP: A 15 cm jet of hot particles that last 30-300 ms

LEFT: Snapshots of a photoignition torch as it ignites an RP-2 fuel spray

RIGHT: Movie of a 50 mg ignition torch that is captured at 2000 fps and shown at 20 fps  Click to play >>>

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How PITCH Works?

- PITCH takes advantage of photo ignition properties of single wall carbon nanotubes (SWNT) that is only a small faction of the fluence needed for the laser ignition
- While other materials show photoignition property SWNT shows a low enough minimum ignition energy (MIE) with a good burns temperature
- For a PITCH we use SWNT along with other energetic materials that is referred to as photoignition solid fuel mixture (SFM)

<table>
<thead>
<tr>
<th>Nanoparticle Samples</th>
<th>Particle Size/ Smallest Dimensional Size</th>
<th>Min. ignition Energy/area, Fluence (mJ/cm²)</th>
<th>Ignition/burn Temperature* (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWNT(51% Fe)</td>
<td>&lt; 30 nm</td>
<td>64 ± 8</td>
<td>490 ± 30</td>
</tr>
<tr>
<td>SWNT(18% Fe)</td>
<td>&lt; 30 nm</td>
<td>182 ± 13</td>
<td>420 ± 50</td>
</tr>
<tr>
<td>Graphene Oxide</td>
<td>&lt; 30 nm thick platelets</td>
<td>500 ± 60</td>
<td>370 ± 100</td>
</tr>
<tr>
<td>Foam/Nanoplatelets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al-nanoparticles</td>
<td>~18 nm</td>
<td>290 ± 50</td>
<td>1100 ± 150</td>
</tr>
<tr>
<td>Fe, Carbon coated</td>
<td>~ 40 nm</td>
<td>220 ± 35</td>
<td>250 ± 30</td>
</tr>
<tr>
<td>Fe powder</td>
<td>~ 30 nm</td>
<td>150 ± 25</td>
<td>220 ± 30</td>
</tr>
<tr>
<td>Pd powder</td>
<td>~ 12 nm</td>
<td>530 ± 60</td>
<td>320 ± 40</td>
</tr>
</tbody>
</table>

MIE for different nanostructured materials and their burn temperatures

*Temp. of a focused spot on the surface of the sample that is ~ 2 mm in diameter
# Content of Solid Fuel Mixtures

<table>
<thead>
<tr>
<th></th>
<th>CNT, PI Agent (Wt%)</th>
<th>Fuel Al_NP (Wt%)</th>
<th>Fuel SRF* (Wt%)</th>
<th>Oxidizer B-KNO₃ (Wt%)</th>
<th>Oxidizer KMnO₄ (Wt%)</th>
<th>Observations and Comments On the Relative Effects of Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>~3%</td>
<td>~97%</td>
<td>~97%</td>
<td></td>
<td></td>
<td>*solid rocket fuel (SRF) ignition is unreliable due to ignition delays (ratio doesn’t matter)</td>
</tr>
<tr>
<td>2</td>
<td>10%</td>
<td></td>
<td>90%</td>
<td></td>
<td></td>
<td>Reliable ignition only &gt;_10 atm with a short burn duration, low gas pressure</td>
</tr>
<tr>
<td>3</td>
<td>10%</td>
<td></td>
<td>90%</td>
<td></td>
<td></td>
<td>Improved ignition reliability &amp; burn Temp. compared to the above</td>
</tr>
<tr>
<td>4</td>
<td>3%</td>
<td>7-12%</td>
<td>85-90%</td>
<td></td>
<td></td>
<td>More reliable ignition, burns at higher Temp. &amp; generates more gas than samples 2 &amp; 3</td>
</tr>
<tr>
<td>5</td>
<td>3%</td>
<td>7%</td>
<td>45%</td>
<td></td>
<td>45%</td>
<td>Less reliable ignition than the above unless the chamber Pres. &gt;_10 atm</td>
</tr>
<tr>
<td>6</td>
<td>3%</td>
<td>7%</td>
<td>50%</td>
<td></td>
<td>40%</td>
<td>Improved flash sensitivity &amp; ignition + generate a lot of gas &amp; smoke</td>
</tr>
<tr>
<td>7</td>
<td>1%</td>
<td>9%</td>
<td>80%</td>
<td>10%</td>
<td></td>
<td><strong>Best ignition sensitivity, reliability &amp; burn duration for Cham. Pres. &gt;_7 atm</strong></td>
</tr>
<tr>
<td>8</td>
<td>2%</td>
<td>8%</td>
<td>70%</td>
<td></td>
<td>20%</td>
<td>Good for chamber Pres. &gt;_15 atm</td>
</tr>
<tr>
<td>9</td>
<td>2%</td>
<td>8%</td>
<td>70%</td>
<td></td>
<td>20%</td>
<td>Improved reliability and burn duration than #8</td>
</tr>
<tr>
<td>10</td>
<td>1%</td>
<td>15%</td>
<td>75%</td>
<td>9%</td>
<td></td>
<td>As good as the above at atmospheric pressure, but burns too fast &gt;_15 atm</td>
</tr>
</tbody>
</table>

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PITCH provides certain advantages over spark ignition systems for rocket engines and combustors:

- PITCH operates within a wide range of pressures and its reaction time (<40 ms) decreases with increased pressure
- It produces no electromagnetic interference (EMI)
- PITCH is photo-activated directly or via an optical fiber so it is not affected by EMI or ESD
- It is self-contained and lightweight using one AA battery

**PITCH also offers unique ignition capabilities in combustor research and development applications:**

- Ignition at target pressure, avoiding potential overheating during pressure ramp-up.

We use PITCH to ignite subscale test rockets at 130 K and ~35 atm (~500 psi) to study potentially destructive CI effects for <3 s, while avoiding overheating.
High Pressure PITCH Applied to a H$_2$/O$_2$ Subscale Rocket Injector

**Top:** a high-pressure chamber for test of subscale rocket injector and its ignition torch

**Bottom:** Movie of a 140 atm (2000 psi) PITCH (top left corner) emitting burning particles.

A 140 atm (2000 psi) PITCH is coupled to a high-pressure test combustion chamber via a 20 cm extension tube (OD=6 mm)

Click >>>

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High Pressure PITCH Applied to an H$_2$/O$_2$ Subscale Rocket Injector

**Top:** A movie of a high-pressure ignition torch igniting a 130 K H$_2$/O$_2$ coaxial jet at 35 atm. The arrow shows the trajectory of the hot particle that causes the ignition.

**Right:** Snapshots of combustion in H$_2$/O$_2$ coaxial jet that was ignited by a PITCH. The combustion was achieved within 25-30 ms after the Xe-flash fires.

Click >>
High Pressure PITCH With Multiple Ignition Capability

Different configurations for placement of Xe-flashes in a PITCH in high pressure canisters offer multiple ignitions. Burst disks allow each section to operate independently. Use of a honey comb configuration provides multiple ignitions before reloading new capsules.

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Conclusion

Specific capabilities of PITCH may present advantages for cold start of combustors and ignition of different turbines:

It provides volumetric ignition by creating a jet of hot gases and burning particles within a wide range of parameters:

- 0.5-100 atm (7-1500 psi) of pressure
- 500-2000°C temperature range
- The ignition delay (10-40 ms) and the burn duration (0.1-2 s) decreases with increased pressure
- Safe and reliable ignition for any combustible fuel mixture
- The low voltage (< 350 v) discharge in PITCH produces no electromagnetic interference and its operation is not affected by EMI or electrostatic discharge
- Use of multiple PITCH igniters greatly enhanced the chance of ignition of turbines
- The connecting tube delivers burning particles directly to the combustion zone, providing big advantages over conventional wall-mounted spark plugs
- PITCH offers a volumetric ignition, unlike point source igniters such as a spark plug, offering an increased chance of ignition for cold start and relight
Possible Areas of Future R&D

Making PITCH work for special application:
• High-pressure ignition of monopropellants, M315E as an example
• Modification of solid fuel mixtures (SFM) for control of ignition energy, burn duration, and burn properties
• Managing ignition transient effects through SFM formulation
• Effects of ambient oxygen on the photoignition process

Use of PITCH as an igniter for space/satellite applications:
• Study of long term stability of different SFM formulations in space environment
• Modification of SFM to prepare PITCH for application in a vacuum
• Control of ignition duration and burn properties for space vehicles
• Ruggedization of PITCH for long time survival in space environment
• A PITCH design with many ignition capsules and a few drive electronics

Photoignition agents as liquid fuel additives:
• Micro encapsulation of SFM in order to use it as an additive for liquid fuels
• Use of the above in specialized fuel injectors in order to achieve distributed ignition in larger rocket engines