Fiber Fuse: its Actions, Behaviors and Control methods

Shin-ichi TODOROKI
NIMS, Japan

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Introduction
A 2009 Nobelist's work (Physics)

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Introduction
Research papers on Fiber fuse

Slide 2

Introduction
Loss reduction of silica fibers

Slide 4
Fiber Fuse: its Actions, Behaviors & Control methods

**Behaviors**
- Why transparent fibers break down?
- Why it propagates to the light source?
- Why the transparent waveguide absorbs light?
- Why it propagates quite slowly?

**Actions**
- What's happening in the spot?

**Control**
- How we eliminate the breakdown?

**Direction**
- Dissipative soliton consuming the energy of laser light

**Heat-up**
- Why the transparent waveguide absorbs light?

**Velocity**
- Why it propagates quite slowly?
**Heat-up**

**Non-linear light absorption**

\[ \text{SiO}_2 \xrightarrow{\Delta} \text{SiO} + \frac{1}{2}\text{O}_2 \]

![Graph showing loss vs. temperature](image)

- Silica fiber (1 m) Koshyp (’88)

**Heat-up**

**Color temperature estimation**

Ex: 1.08 µm silica glass fibers

1: 38 W, 10500 K
2: 9 W, 7900 K
3: 3 W, 4700 K

E. M. Dianov (’06)

IEEE PTL, 18 [6] 752

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**Behaviors**

Why transparent fibers break down?

**Direction**

Dissipative soliton consuming the energy of laser light

**Heat-up**

Thermal decomposition products absorb light.

**Velocity**

Why it propagates quite slowly?

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**Velocity**

Melt → Vaporize → Solidify

\[ \approx \text{W} \]

\[ \approx 1\text{m/s} \]
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**Velocity**

Propagation speed vs. Light power

SMF-28

<table>
<thead>
<tr>
<th>Power density, $P$/mW$\cdot$cm$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>Fusing speed, $v$/m sec$^{-1}$</td>
</tr>
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**Behaviors**

Why transparent fibers break down?

**Direc**tion
Dissipative soliton consuming the energy of laser light

**Heat-up**
Thermal decomposition products absorb light.

**Velocity**
It propagates via melting, vaporizing & consolidation.

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**Fiber Fuse: its Actions, Behaviors & Control methods**

**Behaviors**

It propagates like grass fire consuming light energy.

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**Actions**

What’s happening in the spot?

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**Control**
How we eliminate the breakdown?

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**Actions**

What’s happening in the spot?

**Damage**

What is left after the track of fiber fuse?

**In situ image**
What is told by ultra-high speed photos?

**Periodicity**

Why the voids look like a bullet?
What changed after fusing?
for silica glass fibers:

- $O_2$ gas in the voids
  $\rightarrow$ Raman microscopy (Kashyap '88)
  $SiO_2 \rightarrow SiO + \frac{1}{2}O_2$
- Densification
  $\rightarrow$ refractive index increase (Dianov '92)
  $\Delta n_{\text{max}} \sim 0.012$

Laser power dependence

<table>
<thead>
<tr>
<th>Laser Power</th>
<th>SMF-28 1480 nm</th>
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<tbody>
<tr>
<td>9 W</td>
<td></td>
</tr>
<tr>
<td>7 W</td>
<td>$\leftrightarrow 20 \mu m$</td>
</tr>
<tr>
<td>5 W</td>
<td></td>
</tr>
<tr>
<td>3.5 W</td>
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In situ image

Ultra-high speed videography

- 4 $\mu s$ / frame
- 1 $\mu s$-exposure w/ ND filters ($\times 16$)
- 128$\times$16 pixels
- Wavelength: 380–790 nm
  (as in 2004)

What's happening in the spot?
It leaves periodic & bullet-like voids in core region.

In situ image
What is told by ultra-high speed photos?

Periodicity
Why the voids look like a bullet?
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*In situ image*

Periodicity appears with a tail

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<th>Image</th>
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<tr>
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<tr>
<td>1.5</td>
<td><img src="image4.png" alt="Image" /></td>
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Distance, z/µm

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*In situ image*

Moves with constant velocity during one void generation (20 µs)

<table>
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*Actions*

What's happening in the spot?

*Damage*

It leaves periodic & bullet-like voids in core region.

*In situ image*

It moves with constant speed during 1 void generation.

*Periodicity*

Why the voids look like a bullet?

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*Periodicity*

One day, I had an inspiration.
Periodicity

Sample preparation

Periodicity

Sorting by time reveals the action

Actions
What's happening in the spot?

Damage
It leaves periodic & bullet-like voids in core region.

In situ image
It moves with constant speed during 1 void generation.

Periodicity
Plasma instability makes the tail pinched off & pressed.

OVERVIEW
Fiber Fuse: its Actions, Behaviors & Control methods

Behaviors
It propagates like grass fire consuming light energy.

Actions
Running plasma leaves a void train in the core region.

Control
How we eliminate the breakdown?
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**Control**

How we eliminate the breakdown?

**Stop the spread**

How we terminate the running plasma?

**First extinguish**

How we detect the emergence of the fuse?

**Nip in the bud**

How we eliminate the excess light?

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**Stop the spread**

by destabilizing the plasma

- **Light source**
- **Device**

- Mode field expansion
  - Hand ('89) ⇒ Yanagi ('03)
- Pressure leakage (?)
  - Takenaga ('08)

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**Control**

How we eliminate the breakdown?

**Stop the spread**

by inserting a device that destabilizes the propagation

**First extinguish**

How we detect the emergence of the fuse?

**Nip in the bud**

How we eliminate the excess light?

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**First extinguish**

Freq. analysis of reflected light

- Intensity increase
- Reflection from voids, \( f_c = \nu/p \)
- Doppler shift, \( f_D = 2n\nu/\lambda \)

Abedin ('09)

Control

How we eliminate the breakdown?

Stop the spread
by inserting a device that destabilizes the propagation

First extinguish
after detecting a special signal from the reflected light

Nip in the bud

How we eliminate the excess light?

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Nip in the bud

Description in a patent

• Light absorbing nano-particles in a thin film
  ⇒ Heat-induced light scattering

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Nip in the bud

Devices: Ideals vs. Realized

Optical limiters

Input

Output

Optical fuse

Input

Output

Dynamic Attenuator - Preliminary

Input

Output

Optical limiters are realized using nano technology.

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Control

How we eliminate the breakdown?

Stop the spread
by inserting a device that destabilizes the propagation

First extinguish
after detecting a special signal from the reflected light

Nip in the bud

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**Summary**

**Fiber Fuse: its Actions, Behaviors & Control methods**

**Behaviors**

It propagates like grass fire consuming light energy.

**Actions**

Running plasma leaves a void train in the core region.

**Control**

We have symptomatic treatments, but cannot say safe.

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**References**


2. Movies: [http://www.youtube.com/tokyo1406](http://www.youtube.com/tokyo1406)