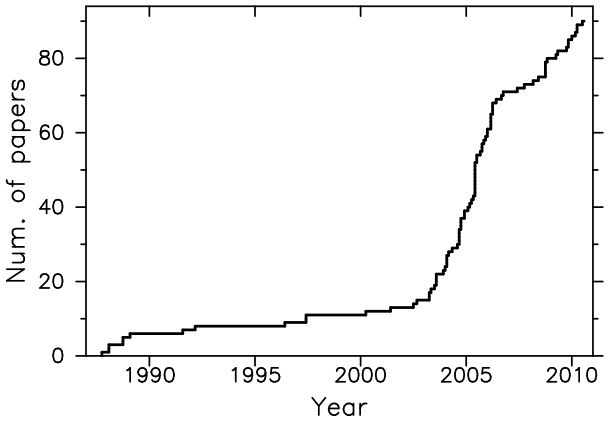
Light & Voids of Fiber Fuse:
precise comparison of in situ image & fused fibers

Shin-ichi TODOROKI NIMS Japan

Slide 1

Introduction

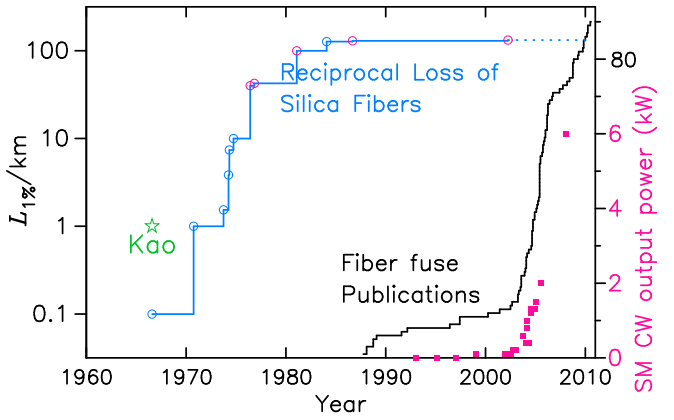
Fiber fuse papers



Slide 2

Introduction

Related history



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Introduction

Fiber fuse research

Macroscopic

- **Simulation**
- **Dissipative soliton**
  Shuto ('03), Yakovlenko, Akhmediev
- **Practical research**
- **Termination**
  Kashyap ('87), Hand, Dianov, ..., Abedin, ...

Theoretical — **Experimental**

- **Capillary instability**
  Atkins ('03), Yakovlenko
- **In situ observation**
  Todoroki ('04), Bufetov

Microscopic

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OVERVIEW

Light & Voids of Fiber Fuse

Review

What is known about its macroscopic behavior?

Model

What did I found 5 years ago?

Evidence

What is newly found with a new video camera?

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Review

What is known about its macroscopic behavior?

Propagation

Ignition

Termination

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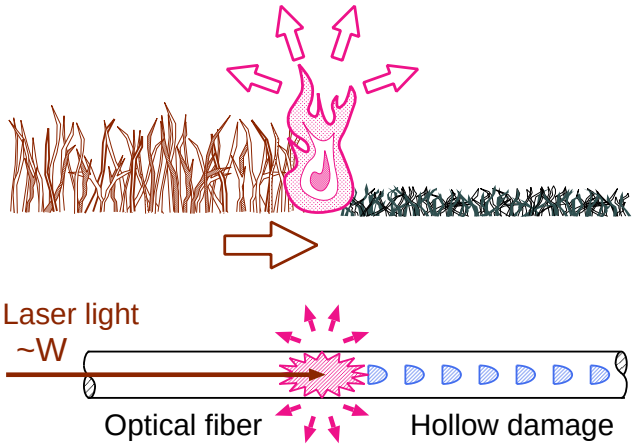
Propagation

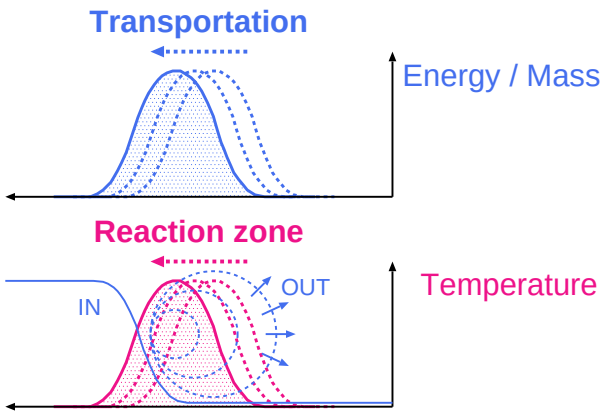
Dissipative soliton



Slide 7

Propagation

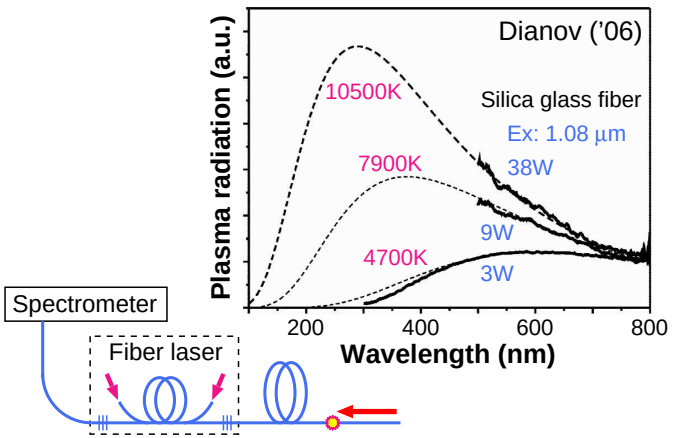
Solitons: Classical vs. Dissipative



Slide 8

Propagation

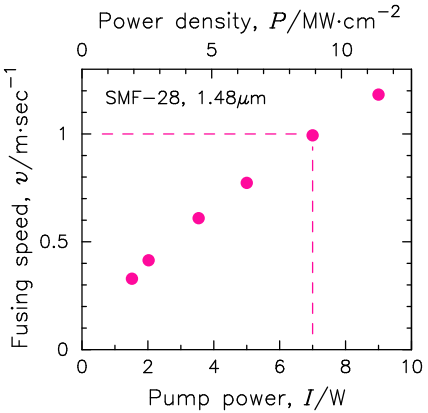
Black body radiation



Slide 9

Propagation

Fusing speed vs. Pump power



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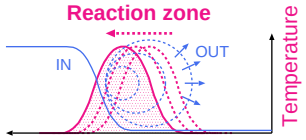
Propagation

Simulation

- Shuto ('03)
- Yakovlenko ('04)
- Akhmediev ('08)

Dissipative soliton



$$T_t = \underbrace{\chi\alpha I}_{} + \underbrace{D\frac{\partial^2 T}{\partial x^2} - k(T - T_0)}_{}$$

Light-induced heat — Diffusion + Relaxation

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Review

What is known about its macroscopic behavior?

Propagation

It runs like a grass fire, balancing btw input & output.

Ignition

Termination

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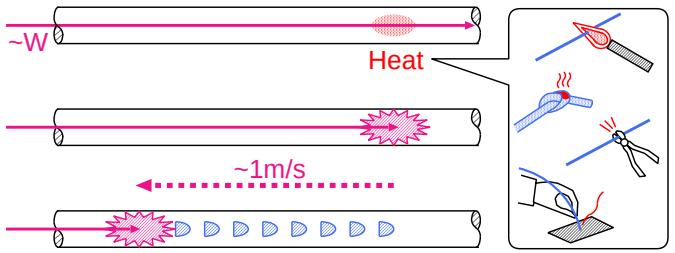
Ignition



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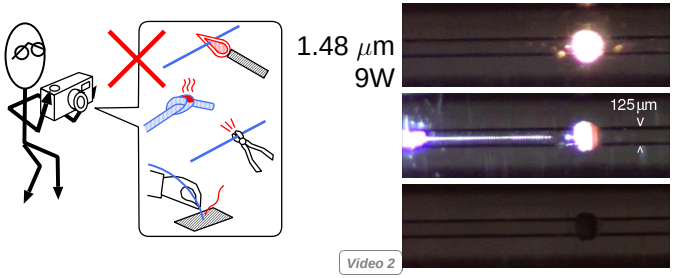
Ignition

Demo video



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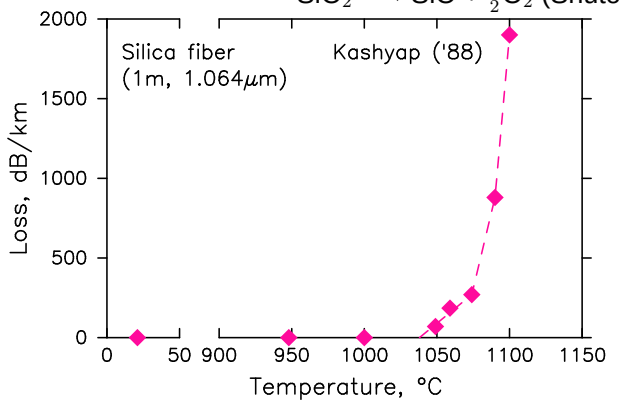
Ignition

Heat induced absorption

$SiO_2 \xrightarrow{\Delta} SiO + \frac{1}{2}O_2$ (Shuto '03)



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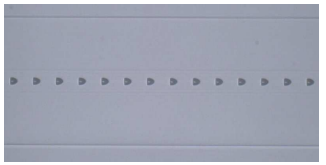
Ignition

Supporting evidence

Silica glass fibers:



- O_2 in the voids
  - ⟸ Raman microscopy (Kashyap '88)

$SiO_2 \xrightarrow{\Delta} SiO + \frac{1}{2}O_2$

- Densification
  - ⟸ Refractive index ↗ (Dianov '92)

$\Delta n_{\max} \sim 0.012$

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Review

It runs like a grass fire, balancing btw input & output.

Propagation

It runs like a grass fire, balancing btw input & output.

Ignition

Heat generates SiO that triggers a positive feedback.

Termination

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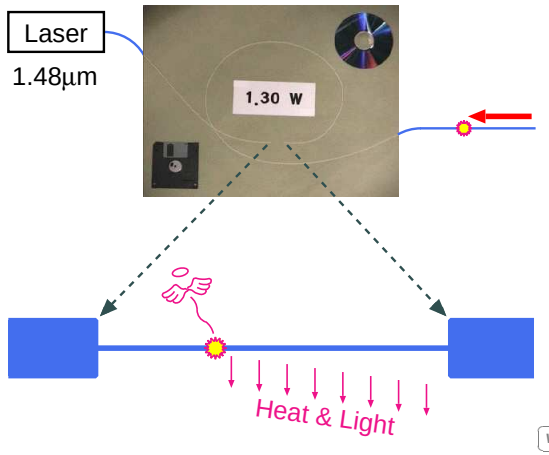
Termination

Demo video



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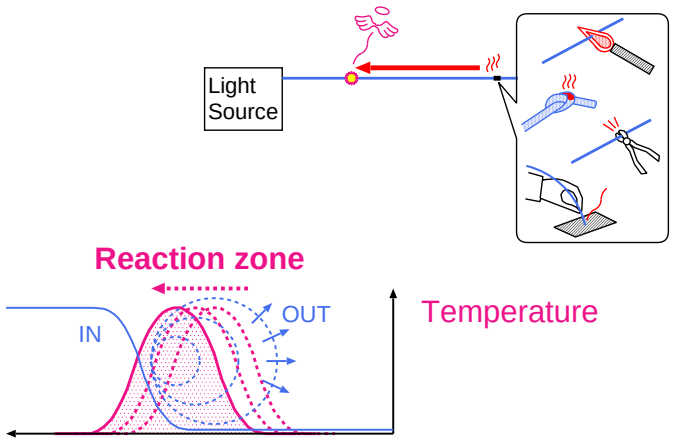
Termination

How can we do?



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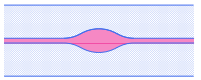
Termination

Enhance the output

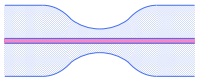
at special devices,

- Mode field expansion
  Hand ('89)⇒Yanagi ('03)



- Pressure leakage(?)
  in a Hole-Assisted Fiber
  Takenaga ('08)

Dianov('04)



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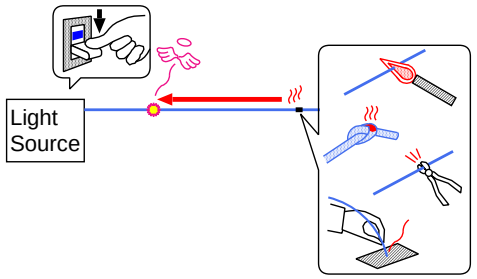
Termination

Reduce the input

after detecting the ignition by



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Review

What is known about its macroscopic behavior?

Propagation

It runs like a grass fire, balancing btw input & output.

Ignition

Heat generates SiO that triggers a positive feedback.

Termination

Devices are designed to break input-output balance.

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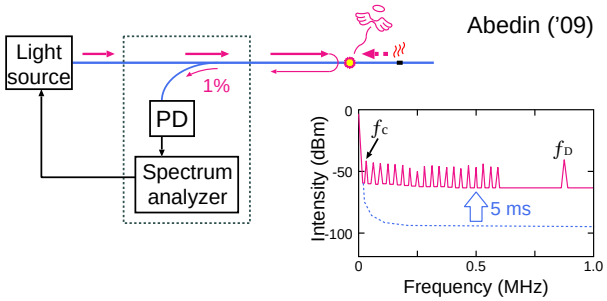
Termination

Reduce the input

after detecting the ignition by

- Reflection from voids, $f_c = \nu/p$
- Doppler shift, $f_D = 2n\nu/\lambda$

Abedin ('09)



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OVERVIEW

Light & Voids of Fiber Fuse

Review

Dissipative soliton: useful to recognize its behavior

Model

What did I found 5 years ago?

Evidence

What is newly found with a new video camera?

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Model

What did I found 5 years ago?

Pattern

How the void train changes its shape with input power?

Origin

What is revealed with an ultra-high speed camera?

Archaeology

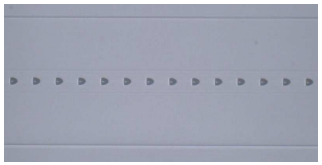
What has been concluded from damage patterns?

Slide 25

Pattern

Laser power dependence

9 W SMF-28, 1.48 μm

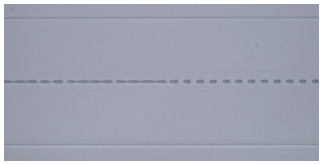


7 W: $\leftrightarrow$ 20 μm

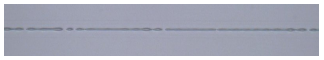
5 W

3.5 W

2 W



1.5 W



1.3 W

1.2 W

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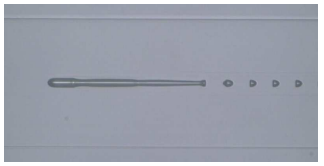
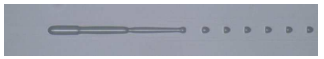
Pattern

Front part of the void train

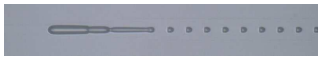
9 W SMF-28 1.48 μm



7 W: $\leftrightarrow$ 20 μm

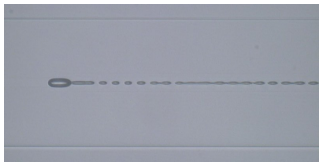


5 W



3.5 W

2 W



1.5 W

1.3 W

1.2 W

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Pattern

Capillary instability

- Rayleigh instability
  Atkins('03)
- Charge repulsion induced on plasma-melt interface
  Yakovlenko('04)

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Model

What did I found 5 years ago?

Pattern

Bullet train appears when the input is more than 2W.

Origin

What is revealed with an ultra-high speed camera?

Archaeology

What has been concluded from damage patterns?

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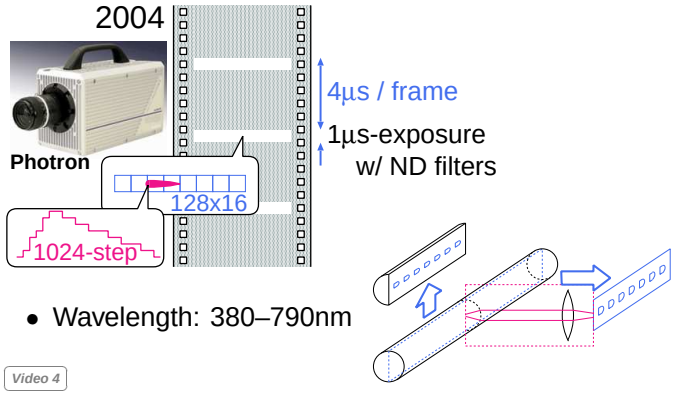
Origin

Ultra-high speed videography

2004



- Wavelength: 380–790nm

Video 4

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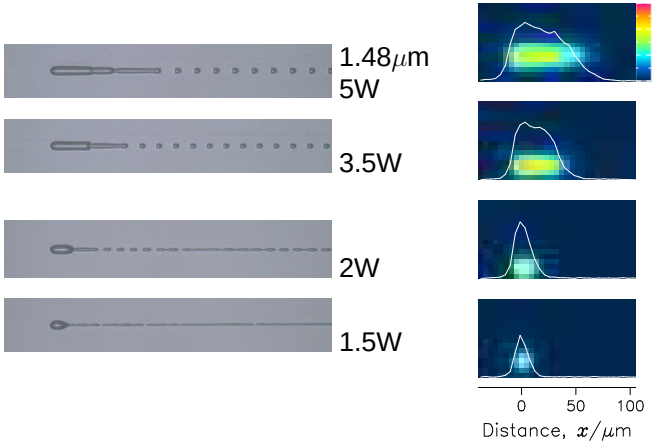
Origin

Periodicity appears with a tail



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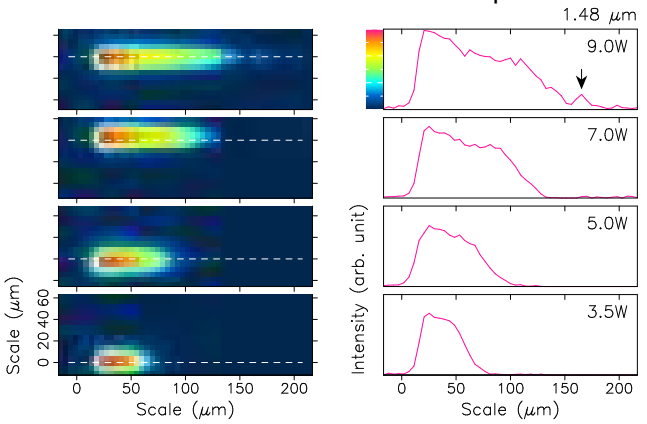
Origin

Difficult to detect light modulations

due to poor resolution



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Model

What did I found 5 years ago?

Pattern

Bullet train appears when the input is more than 2W.

Origin

Tailed plasma leaves periodic bullet-shaped voids.

Archaeology

What has been concluded from damage patterns?

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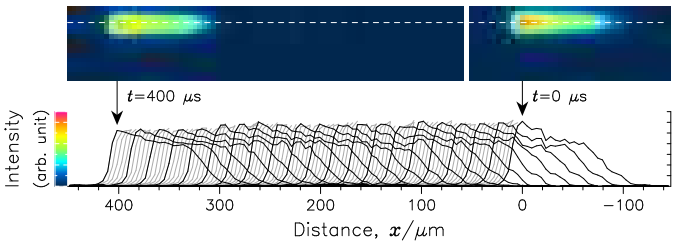
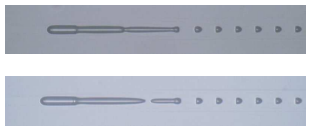
Archaeology

Moves with constant velocity

during one void generation (20 μs)





1.48μm 7W

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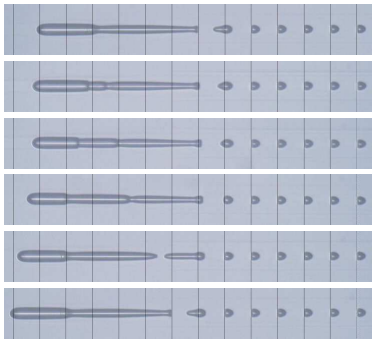
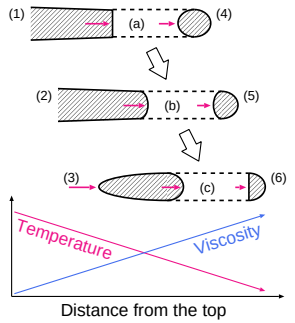
Archaeology

Sorting by time reveals the action



1.48μm 7W



Video 5

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Model

What did I found 5 years ago?

Pattern

Bullet train appears when the input is more than 2W.

Origin

Tailed plasma leaves periodic bullet-shaped voids.

Archaeology

Extended tail is casted off to form one of the bullets.

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OVERVIEW

Light & Voids of Fiber Fuse

Review

Dissipative soliton: useful to recognize its behavior

Model

Tailed plasma must be the source of bullet-like voids.

Evidence

What is newly found with a new video camera?

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Evidence

What is newly found with a new video camera?

High-resolution

What is the new findings about the modulated light?

Examination

What's the relation btw the modulation & the bullets?

Reliability

How reliable the animation of void formation is?

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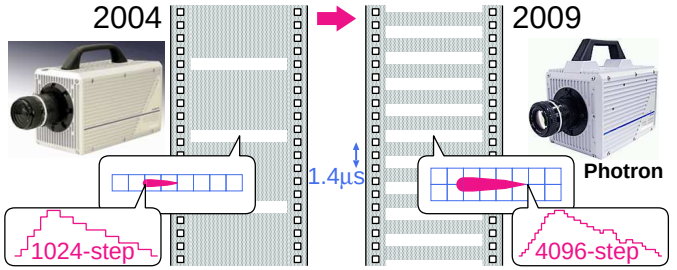
High-resolution

Improved performance



Video 6

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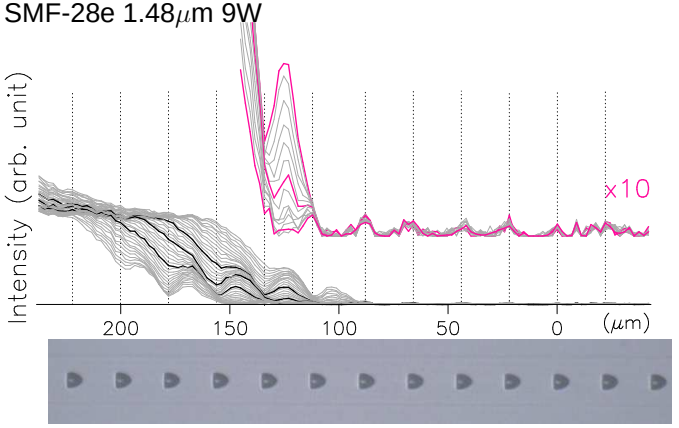
High-resolution

Scattering from the voids

SMF-28e 1.48μm 9W



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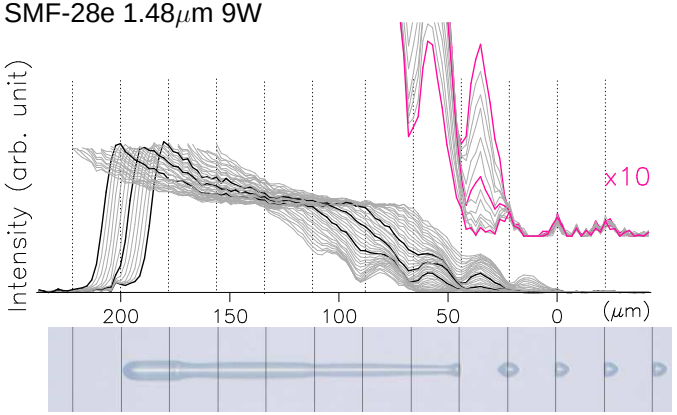
High-resolution

Quenching behaviors

SMF-28e 1.48μm 9W



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Evidence

What is newly found with a new video camera?

High-resolution

Modulated light goes out at between the voids.

Examination

What's the relation btw the modulation & the bullets?

Reliability

How reliable the animation of void formation is?

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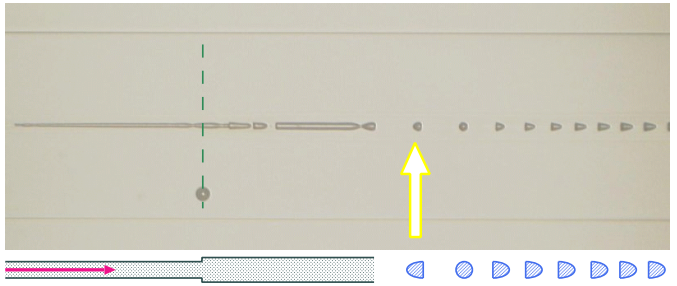
Examination

Reversed bullet appears

near a **HI 1060 / SMF-28e** splicing point,



1.07μm 9W

MFD(μm) 6.2 → 9.2 (1.31μm)

Video 7

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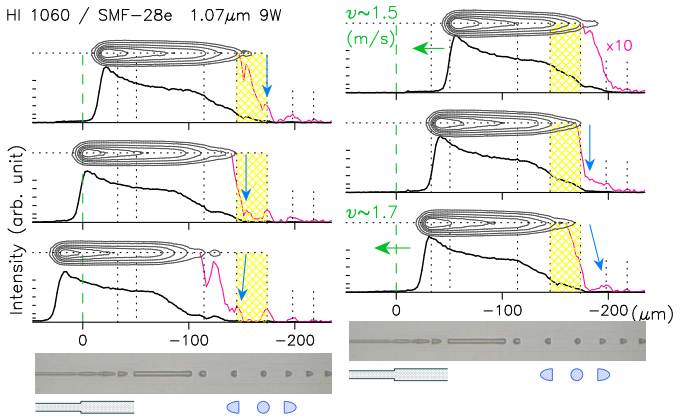
Examination

Different quenching behaviors



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Evidence

What is newly found with a new video camera?

High-resolution

Modulated light goes out at between the voids.

Examination

Shifting direction agrees with the bullet direction.

Reliability

How reliable the animation of void formation is?

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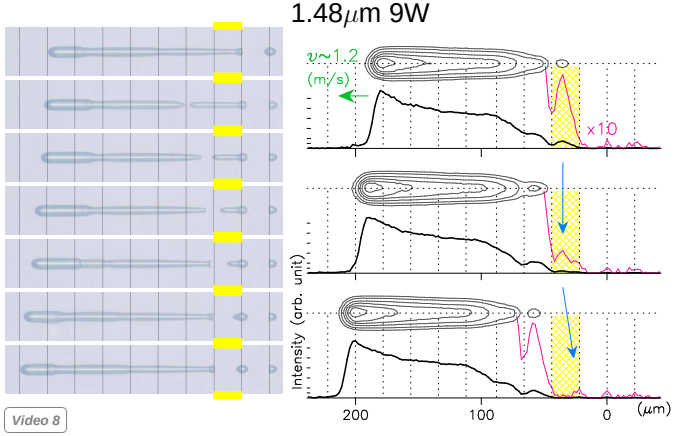
Reliability

Quenched voids vs. in-situ image



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Evidence

What is newly found with a new video camera?

High-resolution

Modulated light goes out at between the voids.

Examination

Shifting direction agrees with the bullet direction.

Reliability

Melt bridge motion is not found in in situ image.

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SUMMARY

Light & Voids of Fiber Fuse

Review

Dissipative soliton: useful to recognize its behavior

Model

Tailed plasma must be the source of bullet-like voids.

Evidence

Bullet-like shape is formed after plasma extinction.

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Acknowledgments

- Photron Co. Ltd.
- Dr. Evgueni M. Dianov
- the late Dr. Sergei I. Yakovlenko

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