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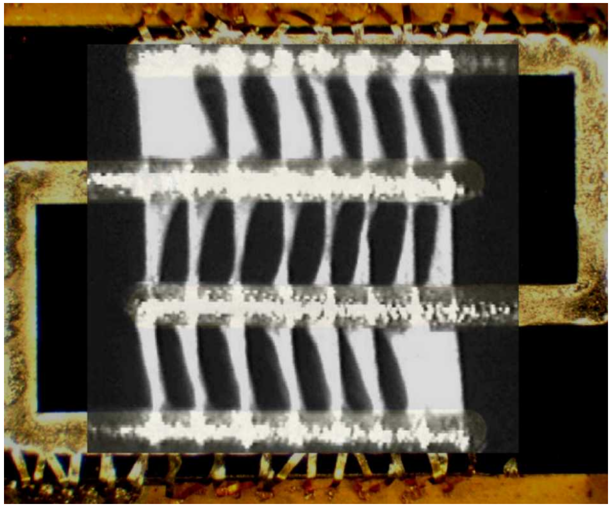

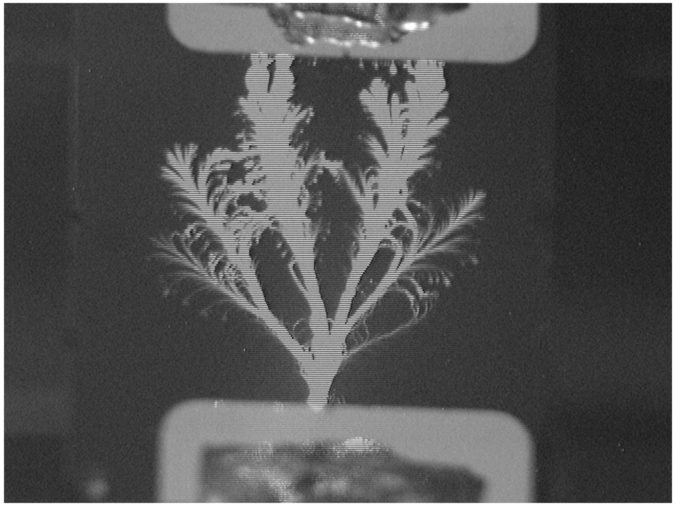

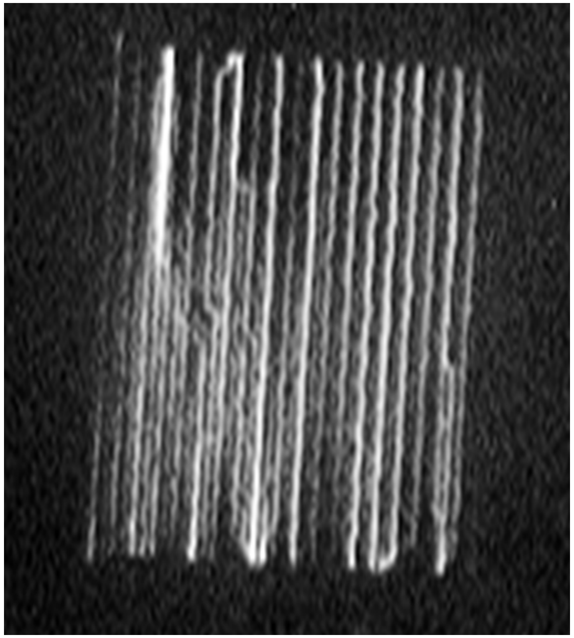

MULTI-FILAMENT PCSS MODULES TO REPLACE HIGH CURRENT PULSED POWER SWITCHES

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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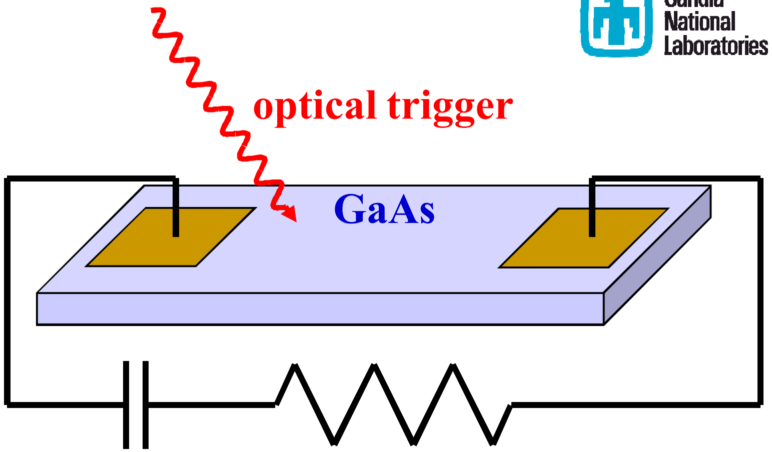
High Voltage GaAs PCSS

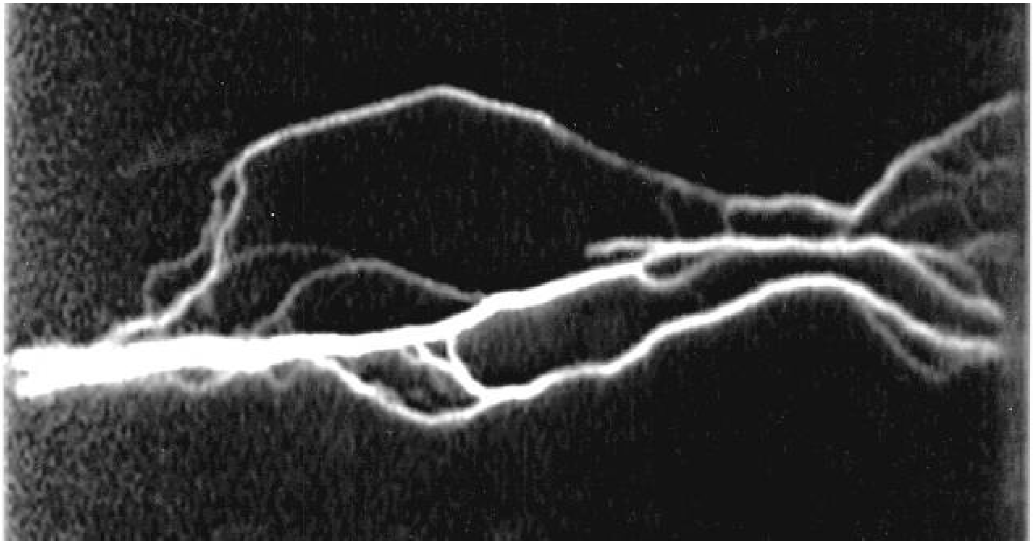
Properties of high gain PCSS :

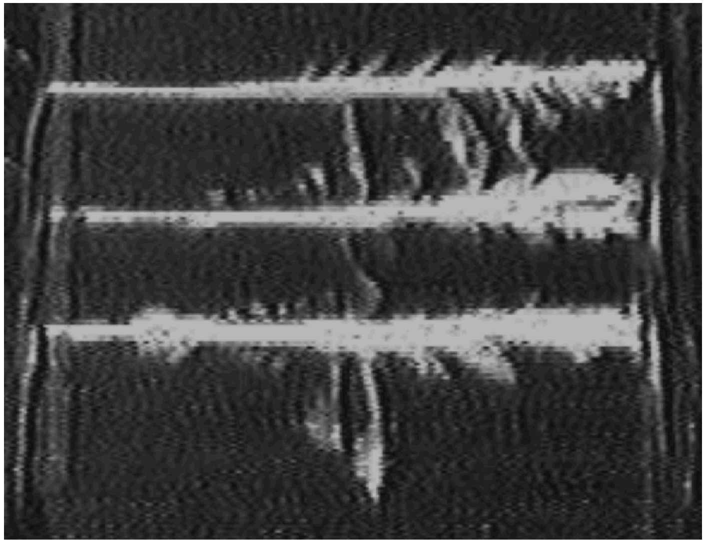
(1) **Low Energy Triggering**
Avalanche carrier generation produces up to 100,000 e/h per photon depending on the circuit

(2) **Current Forms in Filaments**
20 A /filament ➔ 100,000,000 shot lifetime
2 kA /filament ➔ 1 shot lifetime



220 kV, 6 kA
370 ps risetime,
100 ps jitter





PCSS Trigger for an LTD Module

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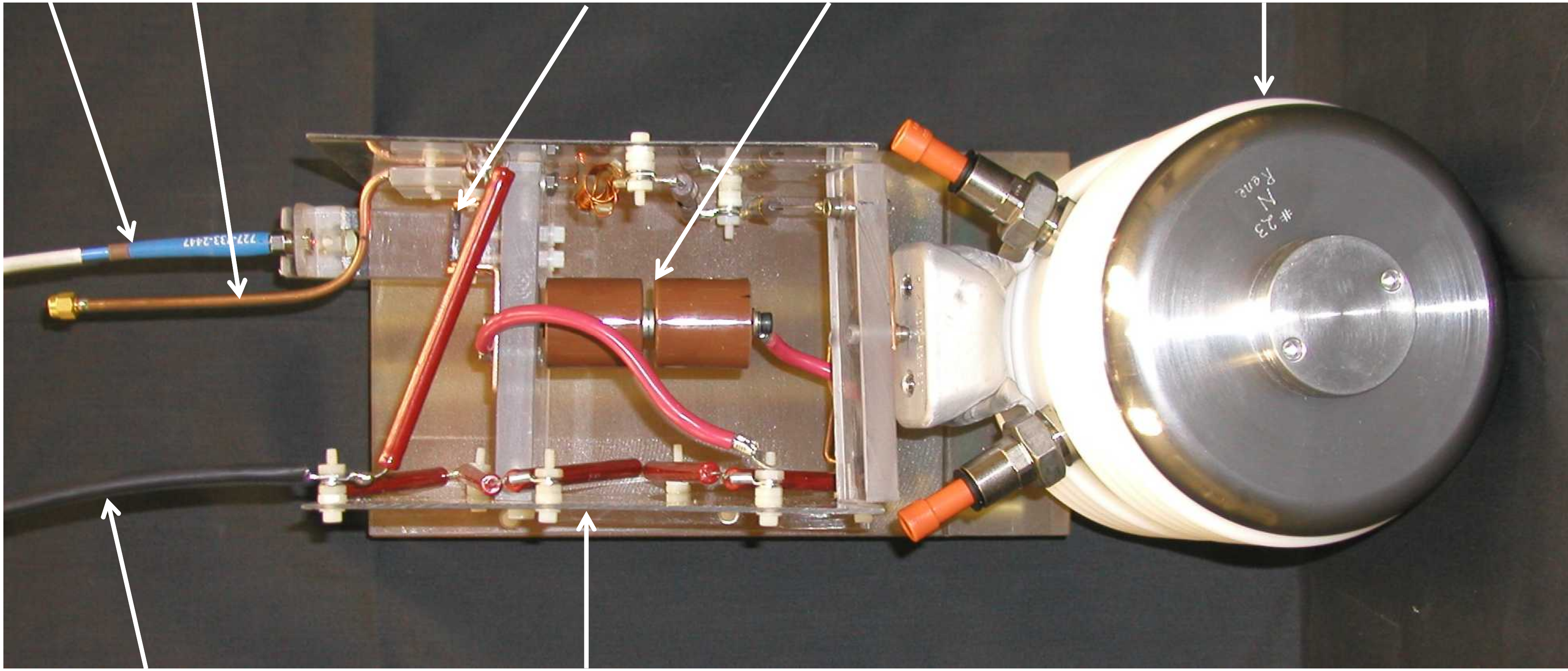
fiber optic trigger

V-dot trigger monitor

PCSS

trigger capacitors

Gas Switch



high voltage supply

voltage divider

Optical Delivery Systems

I. Single (large) laser creating lines of light

A. Line-of-sight optics – clear, stable, straight path
Uniform, parallel beam that can focus to a point

1. **Discrete cylindrical lenses (glass rods)**
2. **Cylindrical lens array** ←
3. Diffractive optics – extinction ratio, uniformity, many devices
   a) Multiple order diffraction grating for monochromatic beam
   b) Spectrum of wide-band ultra-short pulse beam
4. Faceted Mirrors and beam splitters

B. Fiber optics – maintain brightness with narrow lines

1. Single mode – packing fraction
2. **Multi-mode – brightness and spot size**
3. Convert from spots to lines or dashed lines
   a) Mini cylindrical lenses
   b) Tapered fibers
   c) Edge-emitting fibers

Optical Delivery Systems (Continued)

II. Multiple lasers

A. One laser per bank – laser synchronization

B. One laser per filament

1. **Edge-emitting lasers – uniformity and alignment**
   Photo-carrier density: 10^{18} (cm^{-3})
   Trigger Laser Intensity: 80 kW (cm^{-2})
   100 nJ / 5 ns / (10×X2500μJ)
2. **VCSELS – linear VCSELS lase non-uniformly**

C. Many lasers per filament - Fiber lasers – synchronization ←

1. **VCSELS – energy per laser**
2. Fiber lasers – synchronization & cost

III. Patterned substrates with uniform illumination from a single large laser or fiber bundle

A. Masks to block the light between the desired locations ←

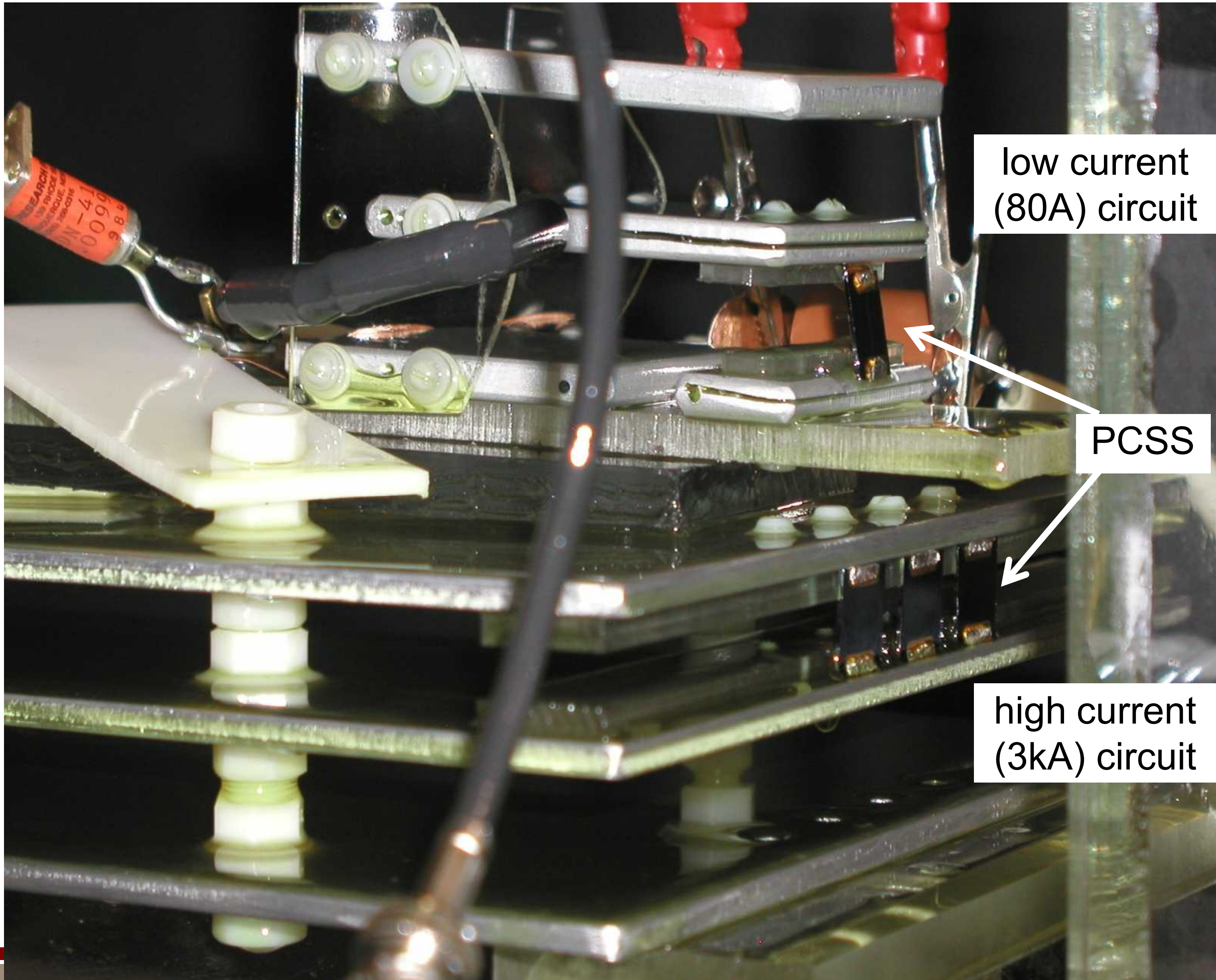
B. Doped/implanted low mobility regions to limit filament growth between the desired locations

C. Etched troughs (ridges and valleys) ←

D. Issues

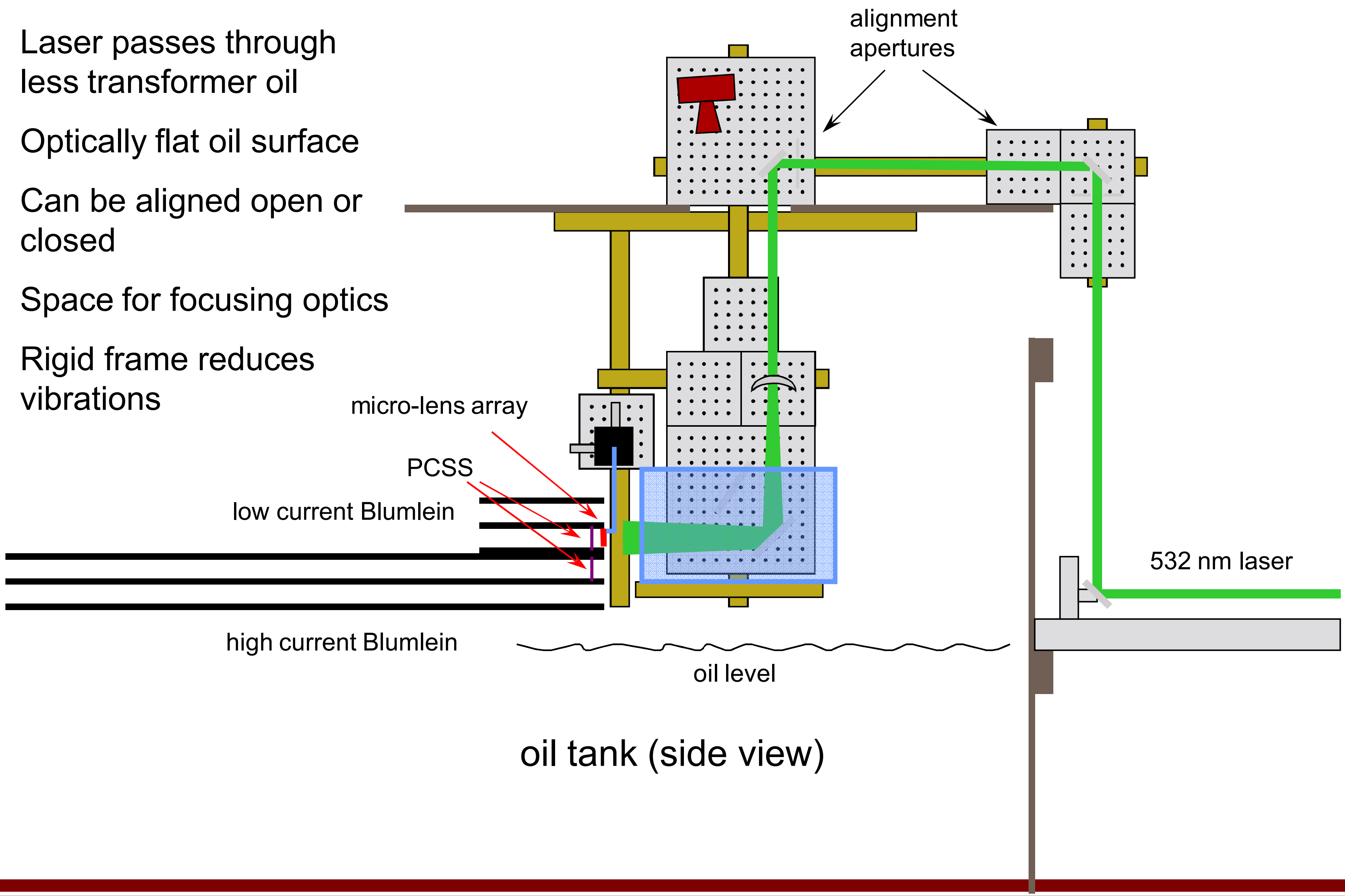
1. Lost light between filaments
2. Depth of the process is small compared to filament diameters

High Current Multiple Filament Testing



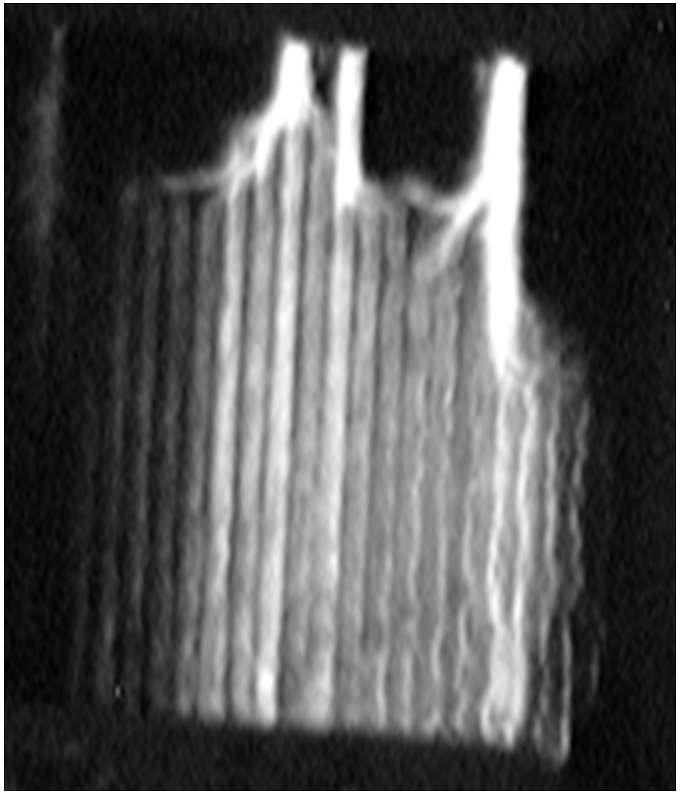
High Current, Multi-Filament, Optical Delivery Path

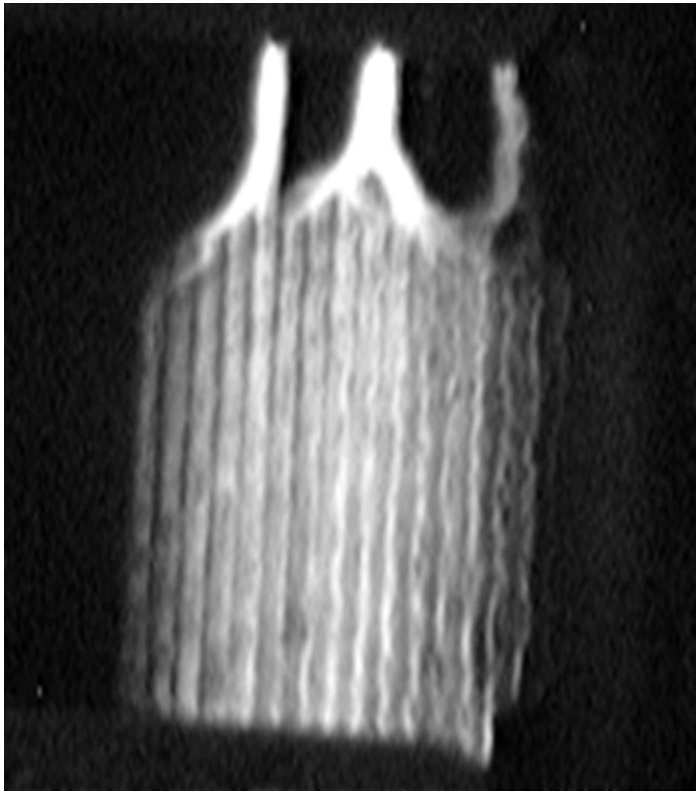
- Laser passes through less transformer oil
- Optically flat oil surface
- Can be aligned open or closed
- Space for focusing optics
- Rigid frame reduces vibrations



Multi-Filament Tests with Micro-Lens Arrays

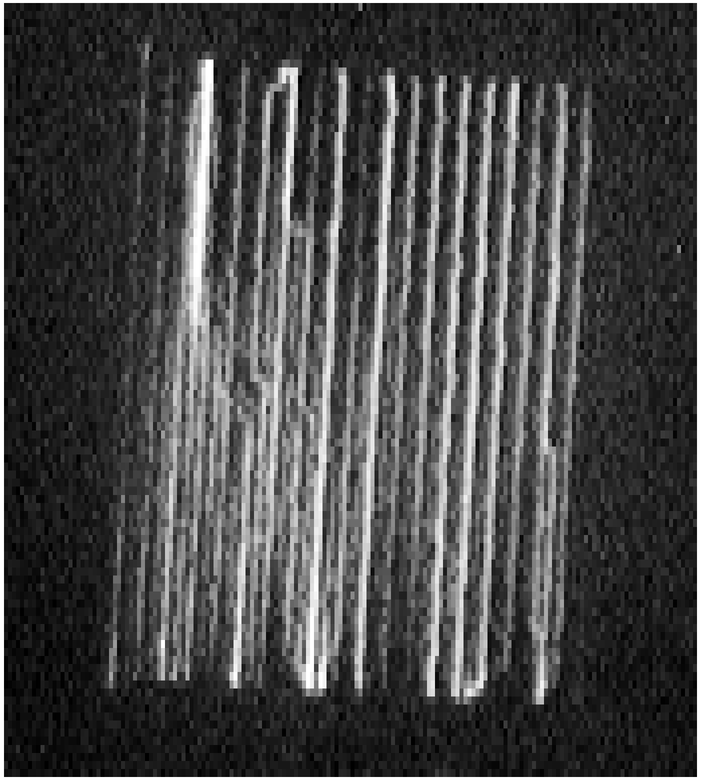
2 stacked micro-lens arrays (shorter focal length)





Multi-Filament Tests with Micro-Lens Arrays

2 stacked micro-lens arrays (better alignment)



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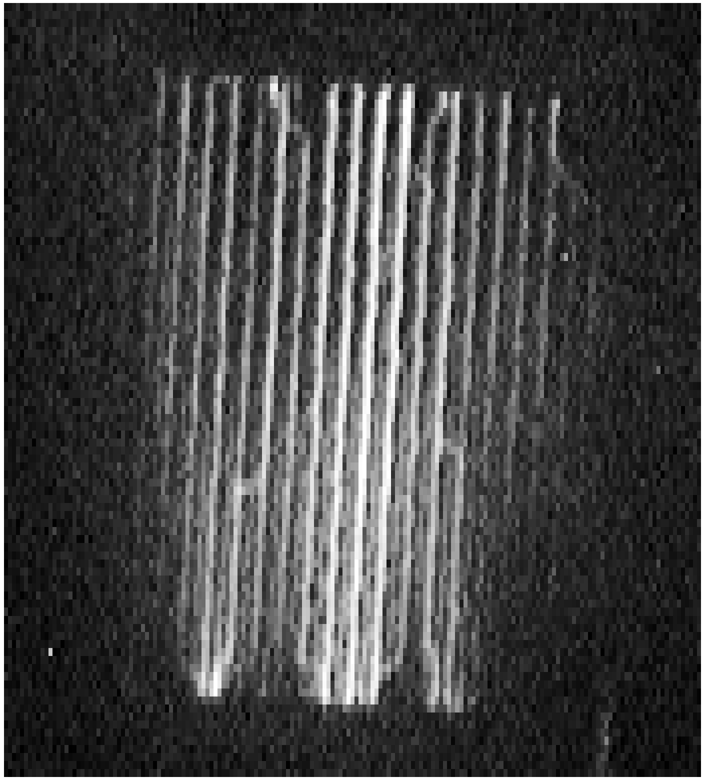

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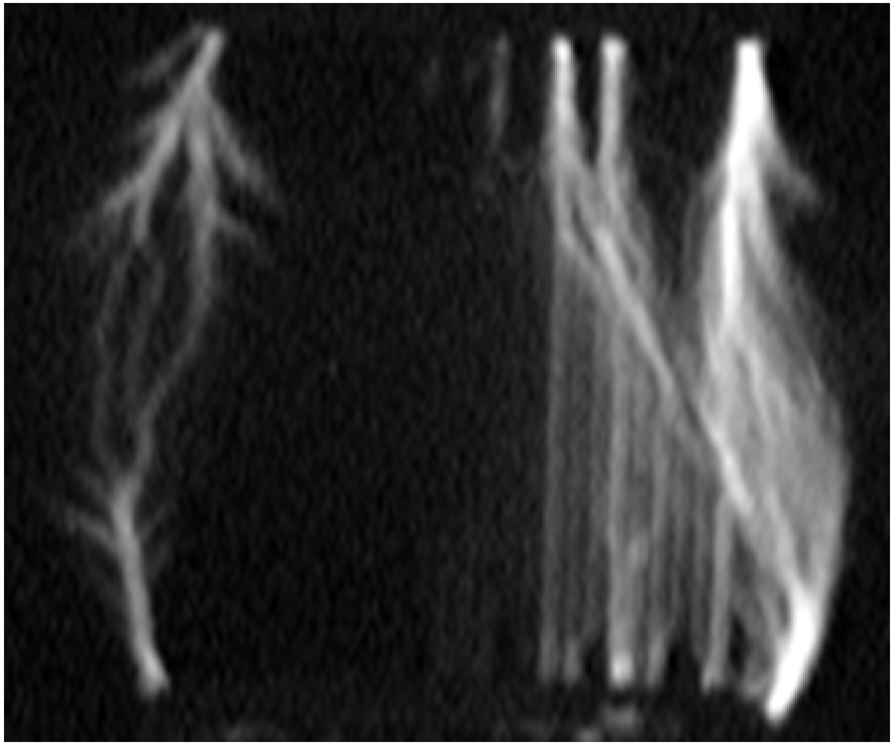
Multi-Filament Tests with Substrate Masks

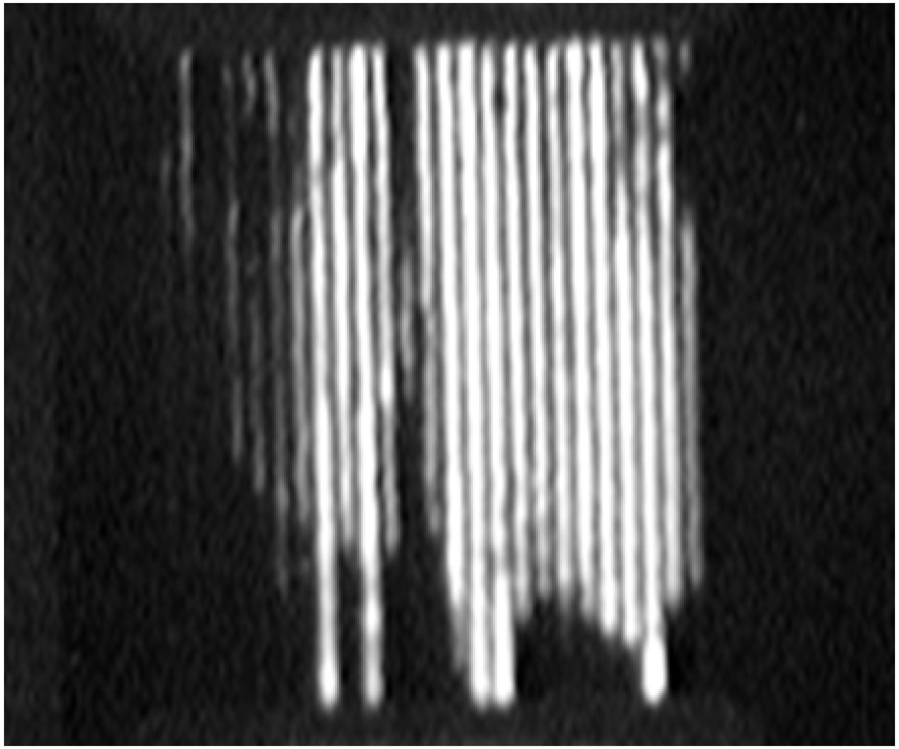
20 um stripes, 330 um spacing



S90.5 – 1.9 mJ

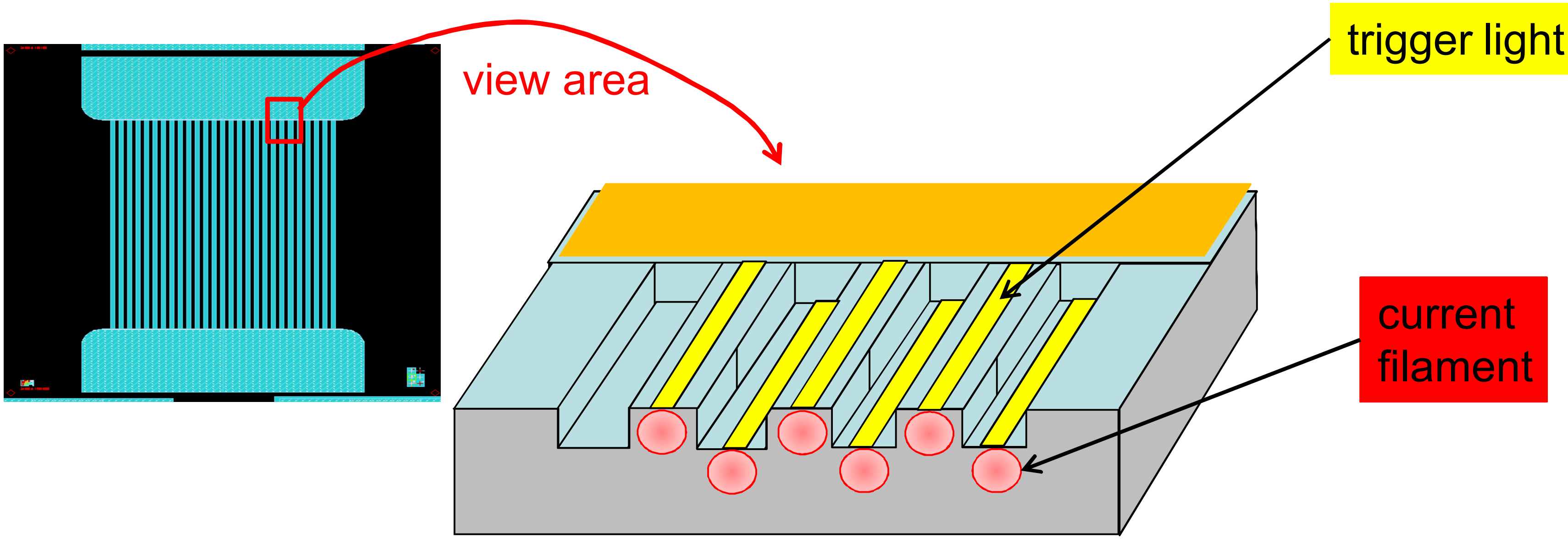
mask flaked off

80 um stripes, 330 um spacing



S28.5 – 1.5 mJ

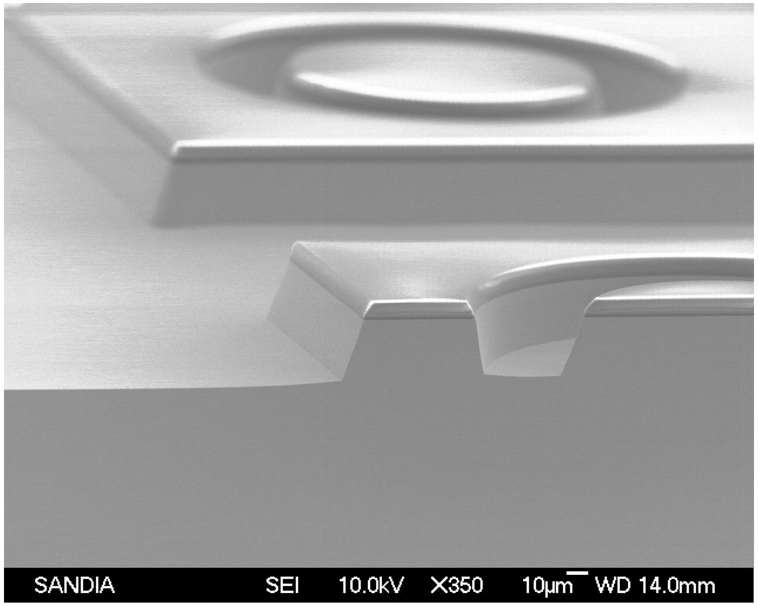
Rib etches to control parallel filaments

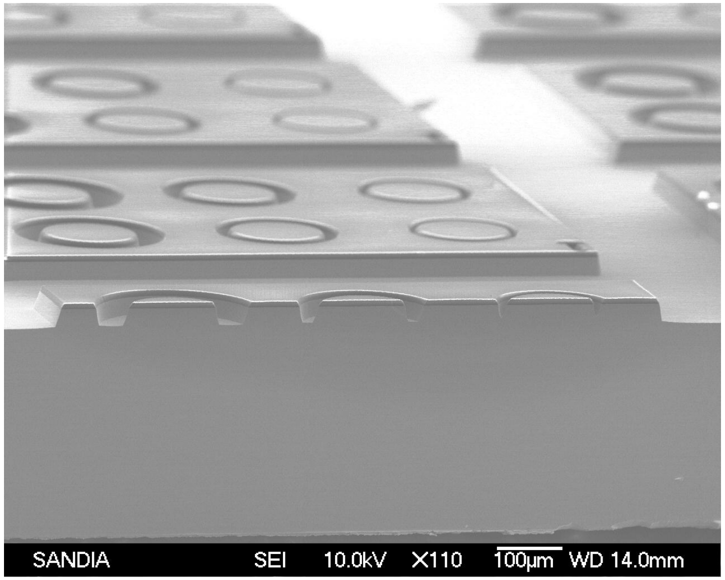


- **Light Isolation: 2 different planes**
- **Filament Isolation: vertical and horizontal distance**
- **Seed carriers determine location, branching happens early without seed carriers**
- **Experiments planned: Image trigger light on rib, on valley, or both**
- **Improve density of filaments**
- **Reduce optical trigger energy**

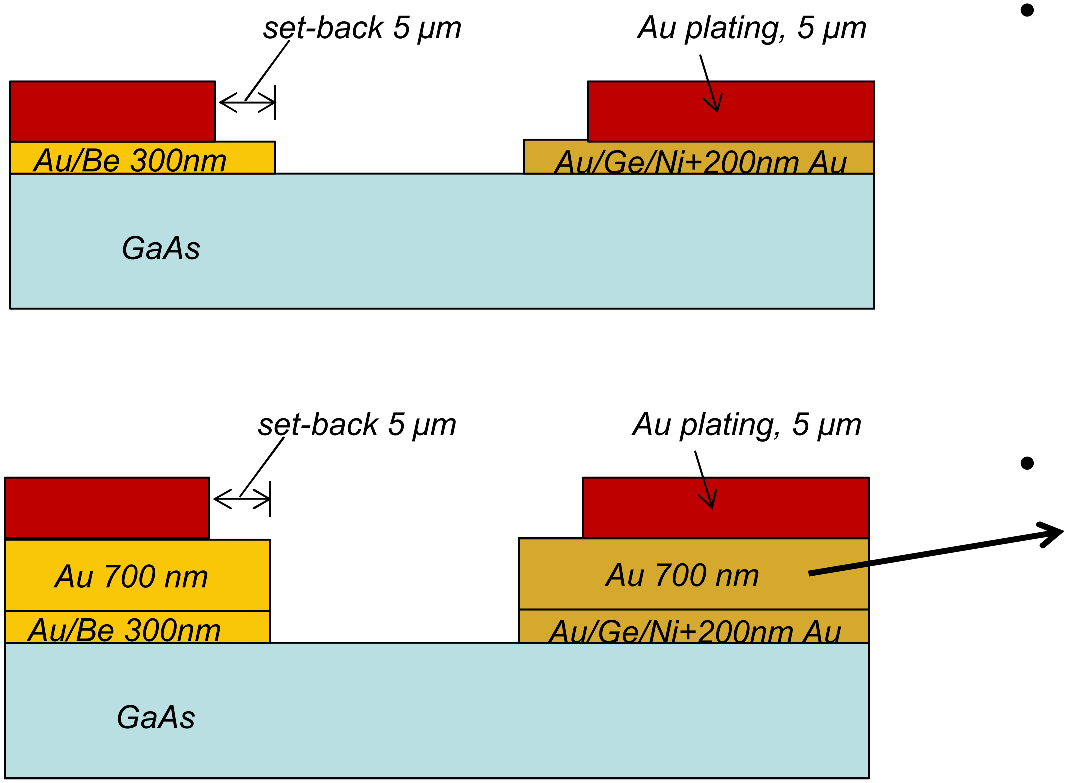
GaAs filament rib etching tests

- 90 min dry etch
- ~30 um etch depth
- grooves wider than 50 um are nearly as deep as “semi infinite” grooves



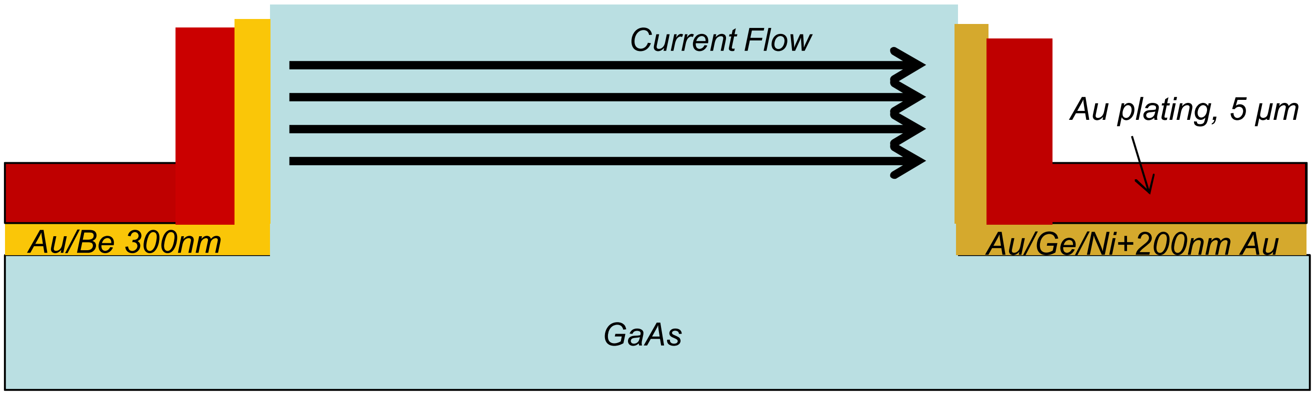


Thick contact design



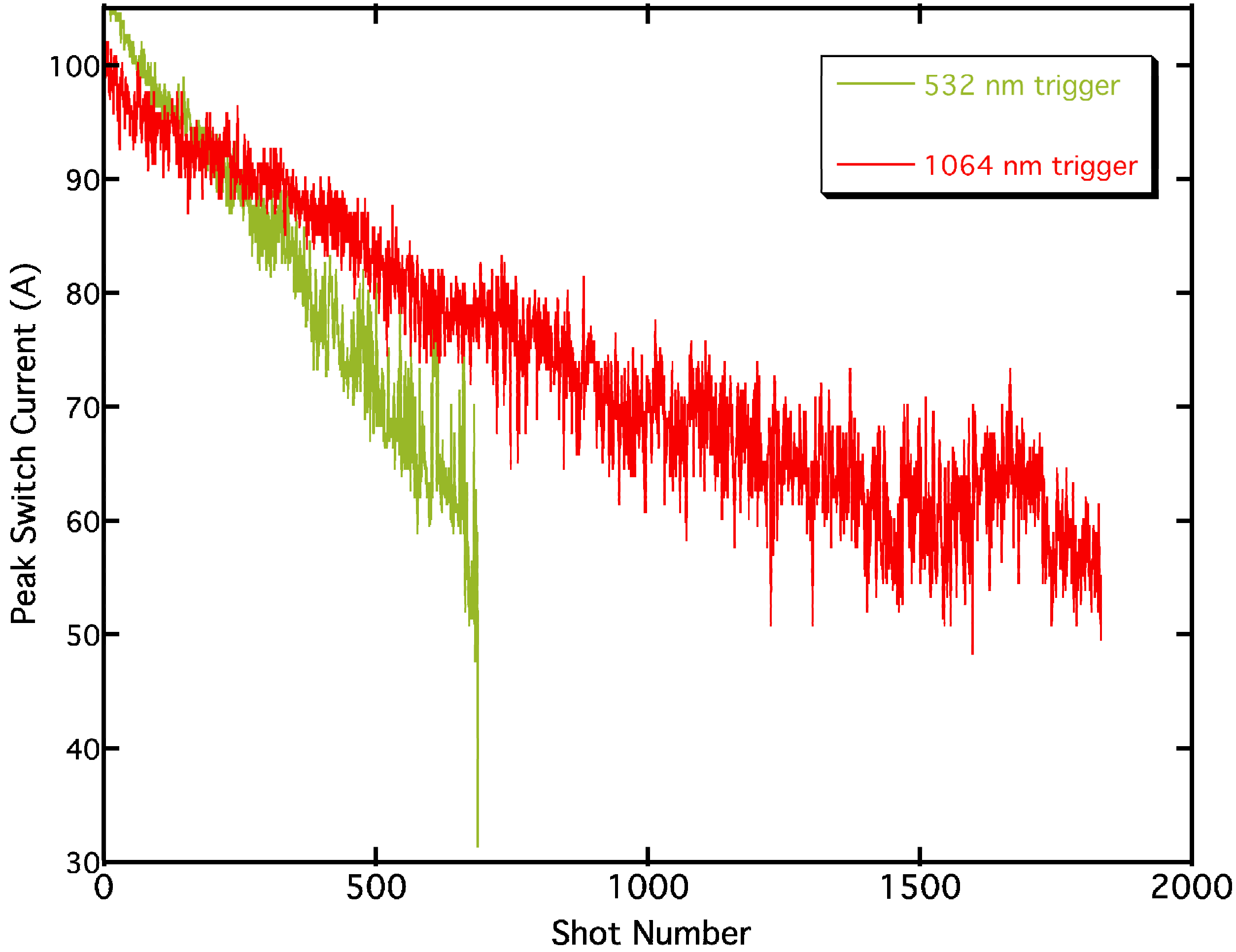
- **prior HV switches were built with fairly thin metal at the edge of the contact**
  - leading edge burns away with repeated shots
- **Thick contact design triples the leading edge thickness to 1 um**
  - goal is better heat transfer away from edge and into the plated metal

Vertical Contact Design



- **One ideal configuration is to terminate the filament current in a metal contact perpendicular to the E-Field**
  - Reduce current density and heating
  - Improve current handling and PCSS life

PCSS Lifetime Dependence on Trigger Wavelength



- 532 nm strongly absorbed at the surface

  initially switches higher peak current
- 1064 nm weakly absorbed in GaAs, may initiate filaments deep in the bulk with lower current density for improved contact lifetime

Filament Formation Dependence on Optical Trigger Energy

5uJ Trigger energy

18.2 | 21.3 | 13.0 | 22.5

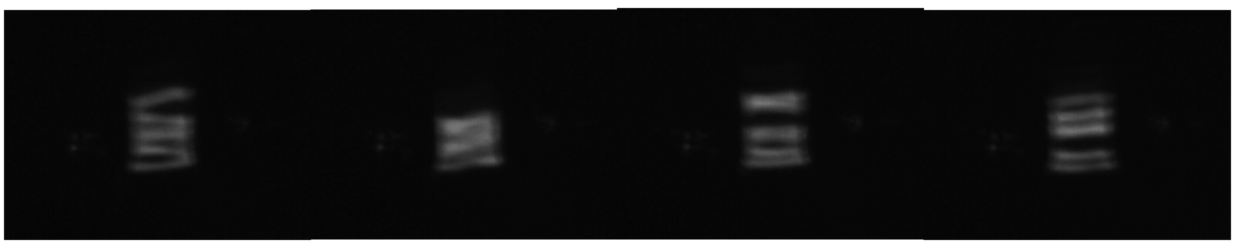
18.75 Peak – Average Brightness ratio

50uJ Trigger energy

12.5 | 11.8 | 18.2 | 15.5

14.50 Peak – Average Brightness ratio

100uJ Trigger energy



9.48 | 12.4 | 12.6 | 11.9

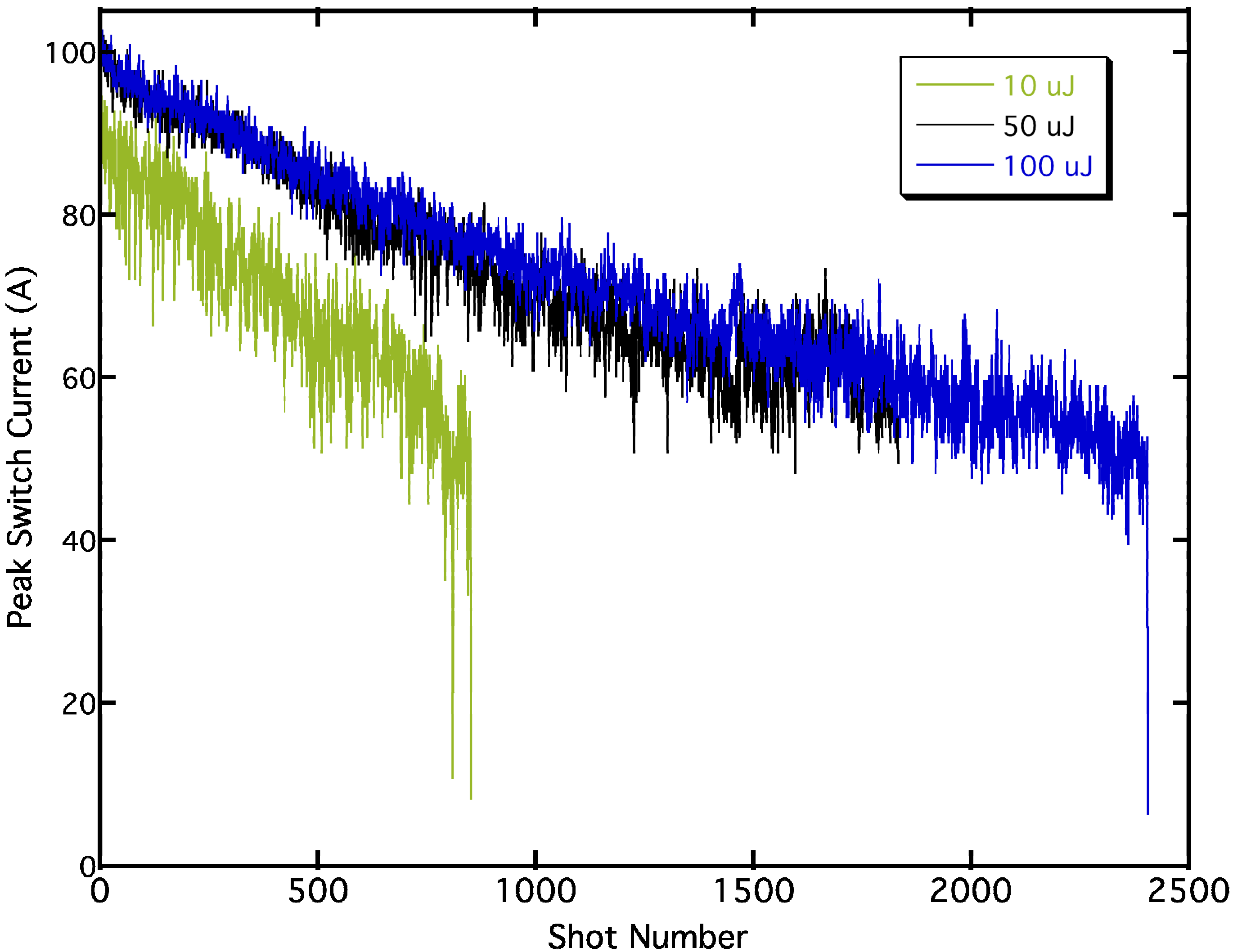
11.595 Peak – Average Brightness ratio

Same nominal total current for all filament images (~100A)

Higher peak brightness for filaments triggered with lower optical energy

Higher Optical Trigger Energy Results in Reduced Peak Current Density

PCSS Lifetime Dependence on Trigger Energy



Reduced peak current density at higher trigger energy improves lifetime

Conclusions

- Improving current sharing with multiple filament PCSS
- Optical trigger delivery approaches:
    1. μ-lens arrays
    2. optical trigger masks
    3. etched ribs & valleys
- Improving contacts for more current per filament
- Testing above and below band gap triggering