Axicons and Nanowires

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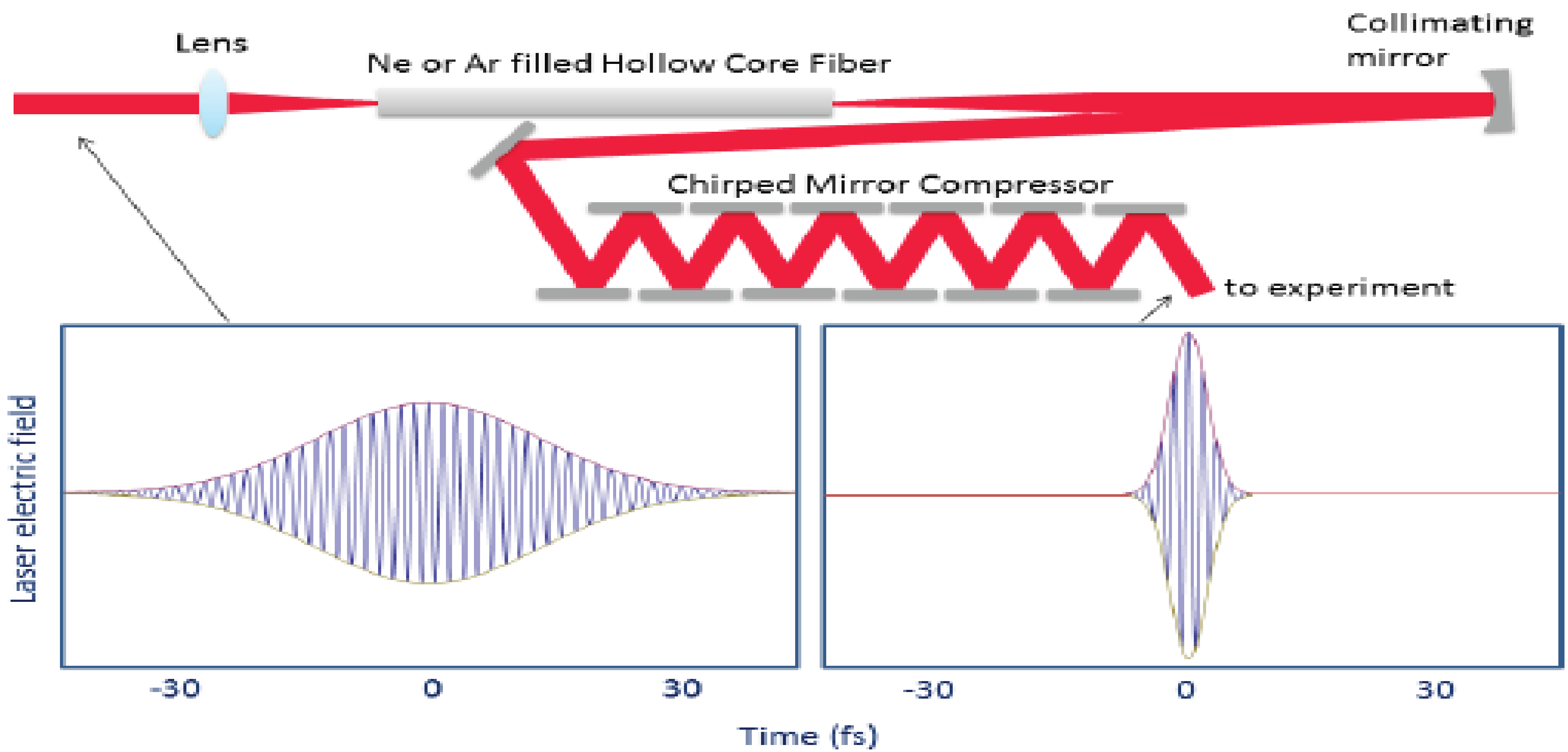
Axicon Project

- Increase efficiency of power transmission through a hollow core fiber
- Propagation through fiber reduces output power
- Initially create Bessel beam using Axicon lens

Objectives:

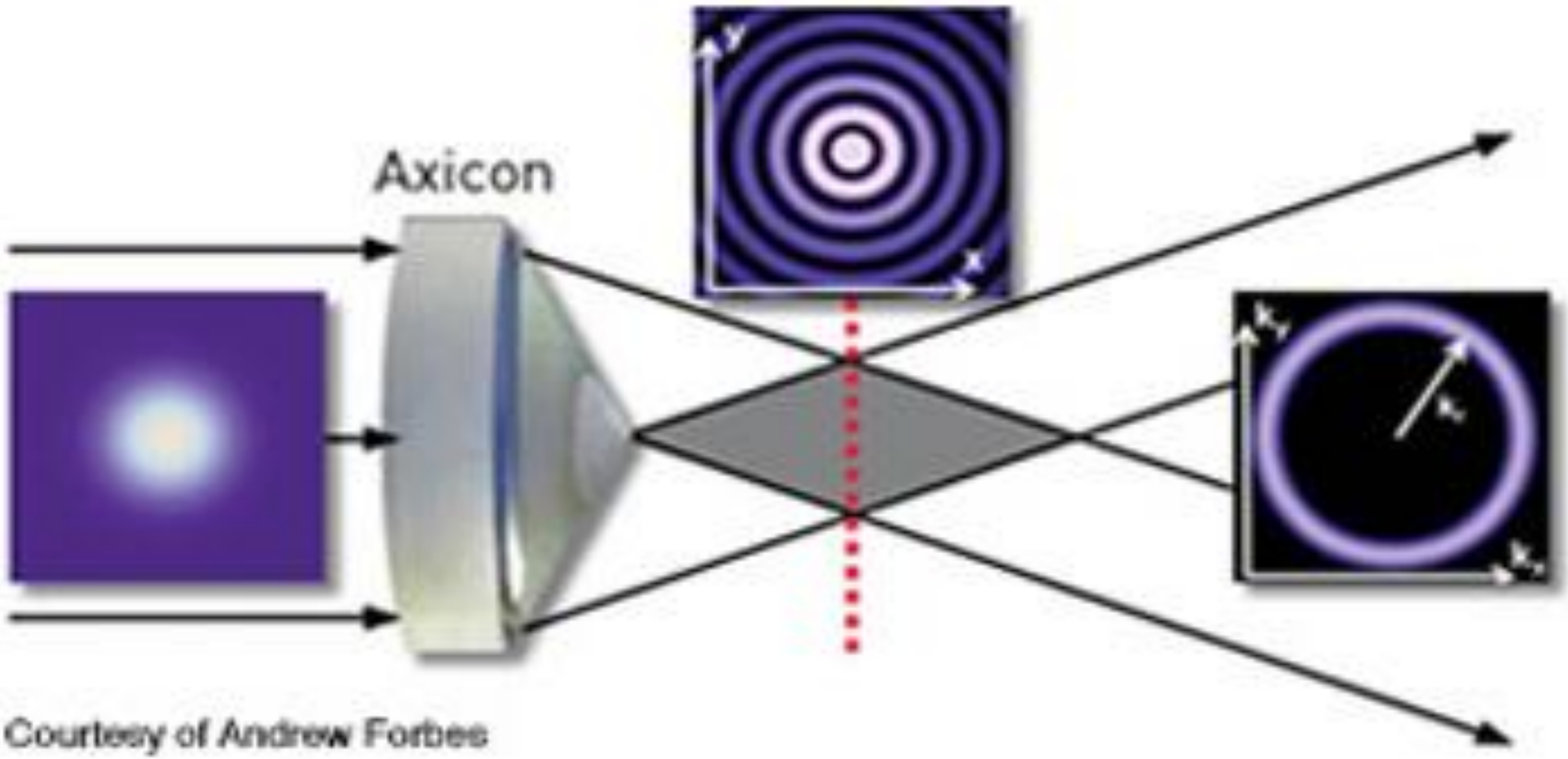
- Generate Bessel beam with Axicon
- Propagate Bessel beam through hollow core fiber
- Characterize the Bessel beam by fitting a spatial mode

Motivation



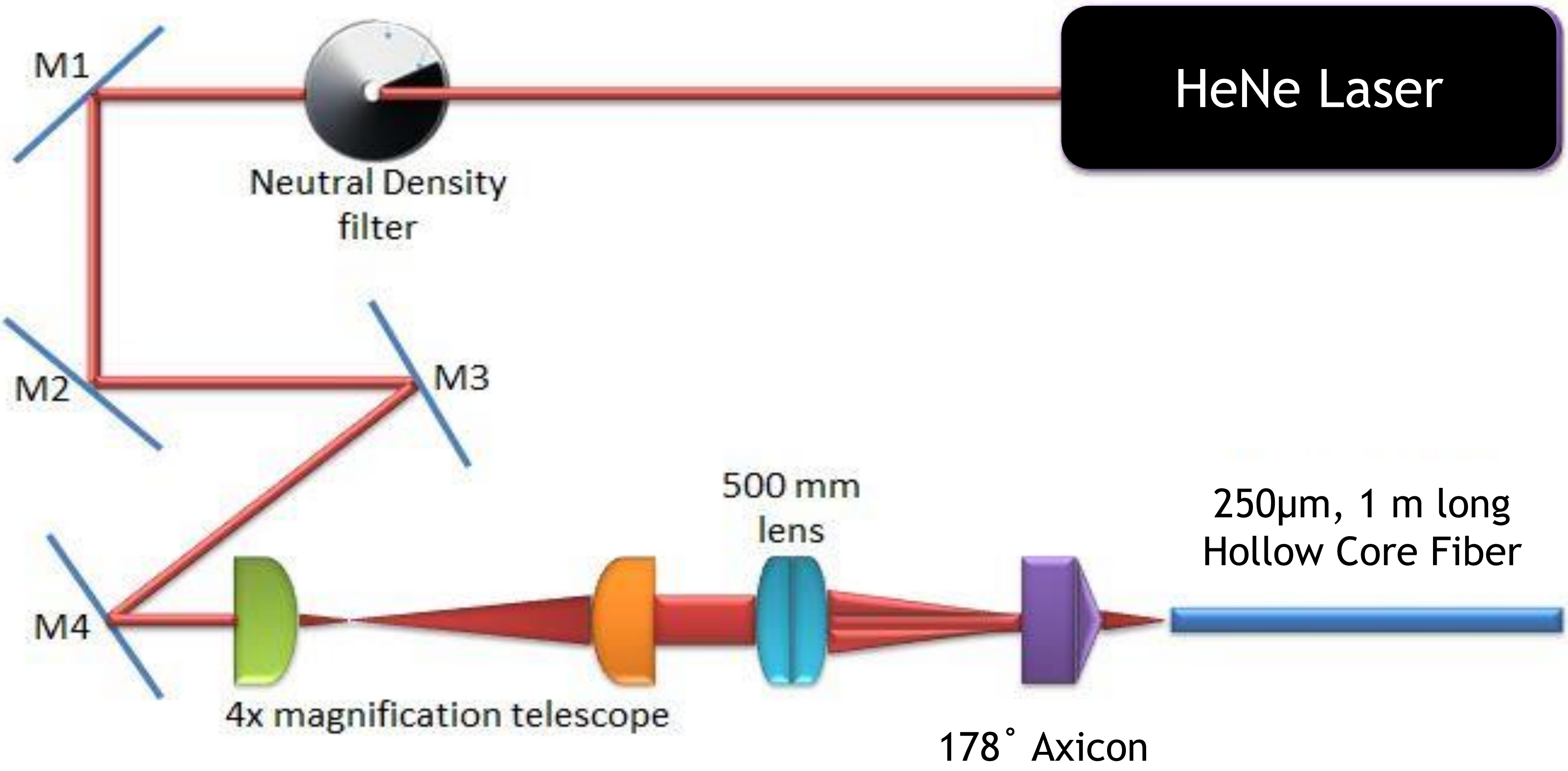
- Propagation through gas and fiber reduces initial pulse duration
- Initial Gaussian converted into short, few-cycle Bessel beam, losing power
- Hope to reduce loss by initially producing a Bessel beam

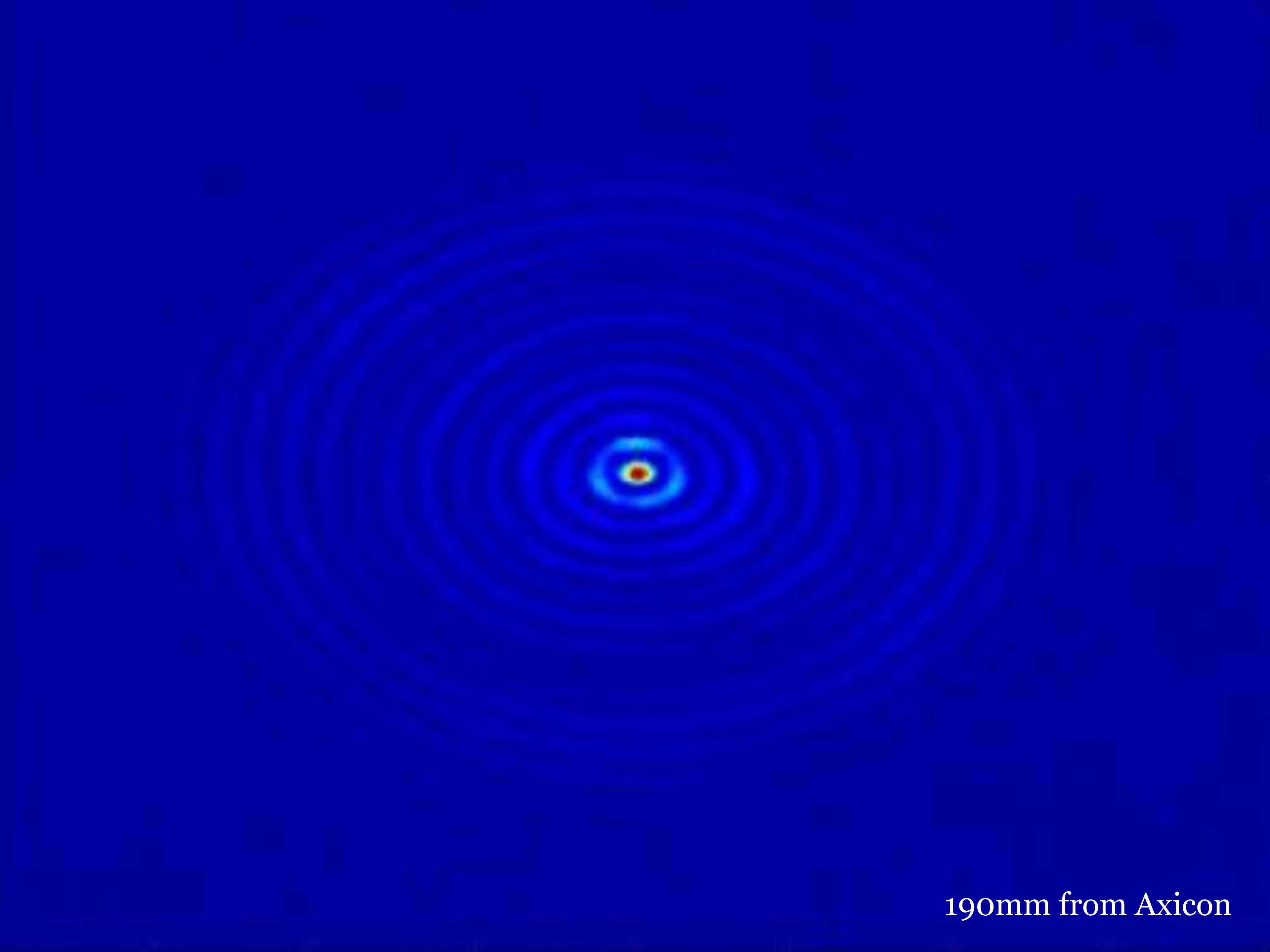
Figure: Kling, N. *Controlling the dynamics of electrons and nuclei in ultrafast strong laser fields* (Doctoral dissertation)



- Representation of the Axicon and Bessel beam.
  - Incoming Gaussian, near-field Bessel and far-field Bessel.
- Center mode intensity drops, leaving characteristic ring

Axicon Experimental Setup





190mm from Axicon

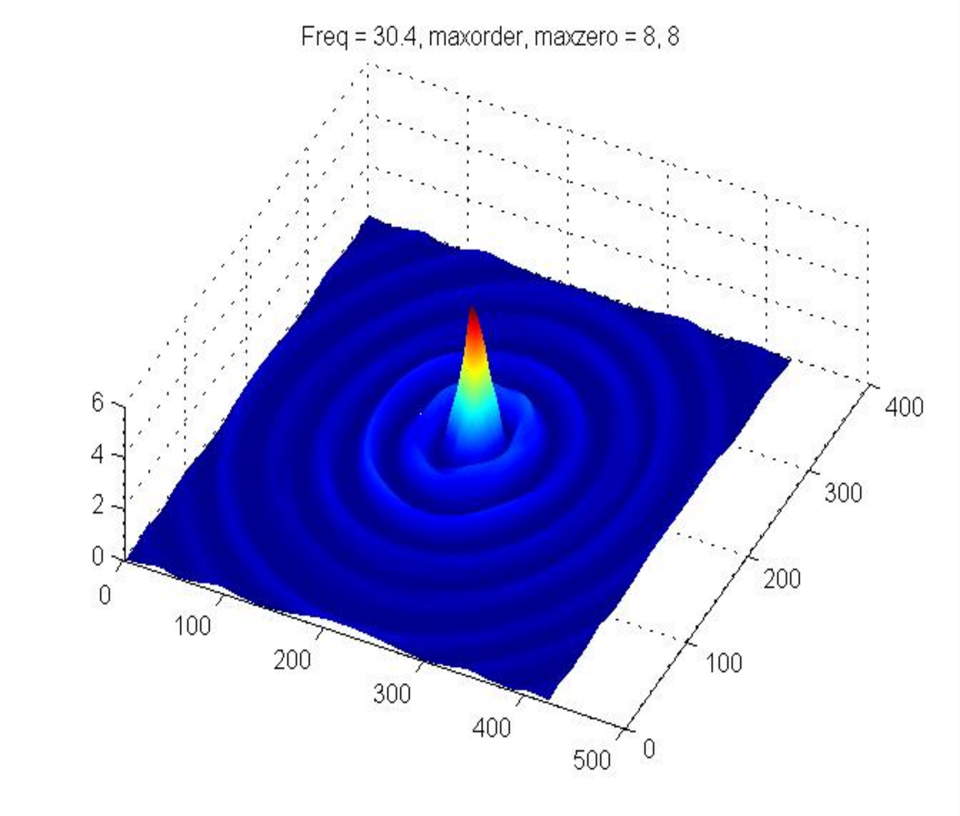
Fitting the Image

- We produced MATLAB code that deconstructed an image (S) into a series of Bessel functions
- Differing orders n (J_n) and associated coefficients (c_{nm}).

$$S(r,\theta) = \left| \sum_{m=0}^{M} \sum_{n=0}^{N} c_{nm} J_n(\alpha_n^m r/p) e^{in\theta} \right|^2$$

$$c_{nm} = \int_0^a \int_0^{2\pi} J_n(\alpha_n^m r/p) e^{in\theta} \sqrt{S(r,\theta)}\, r\, dr\, d\theta$$

Original Image



Fitted Image

- Detailed 3-D plot of intensity of Bessel beam against radial distance from center
- Used up to eight orders and eight zero's for each order.
- The frequency or parameter p in the equation was found to be 30.4 pixels.

Axicon Results

- Attempting to couple into multiple hollow core fibers
- Initial power of HeNe: 3.72 mW

Inner Diameter (µm)	Transmitted Power (mW)	Efficiency (%)
250*	2.08	**55.9**
300	0.36	9.7
350	0.78	21.0
400	0.77	20.7
450	0.48	12.9
500	0.40	10.8
Lens**	2.32	**57.6**

- *This fiber was 39.5 in and a different brand than compared to all other fibers which were 48 in long. Not much is known about the quality of the 300-500µm fibers, so the data may not represent an accurate finding.
- **This measurement was taken without the axicon, using only the lens and 250µm fiber. The efficiency is calculated from an initial power of 4.03mW since no energy was lost by reflections of the axicon.

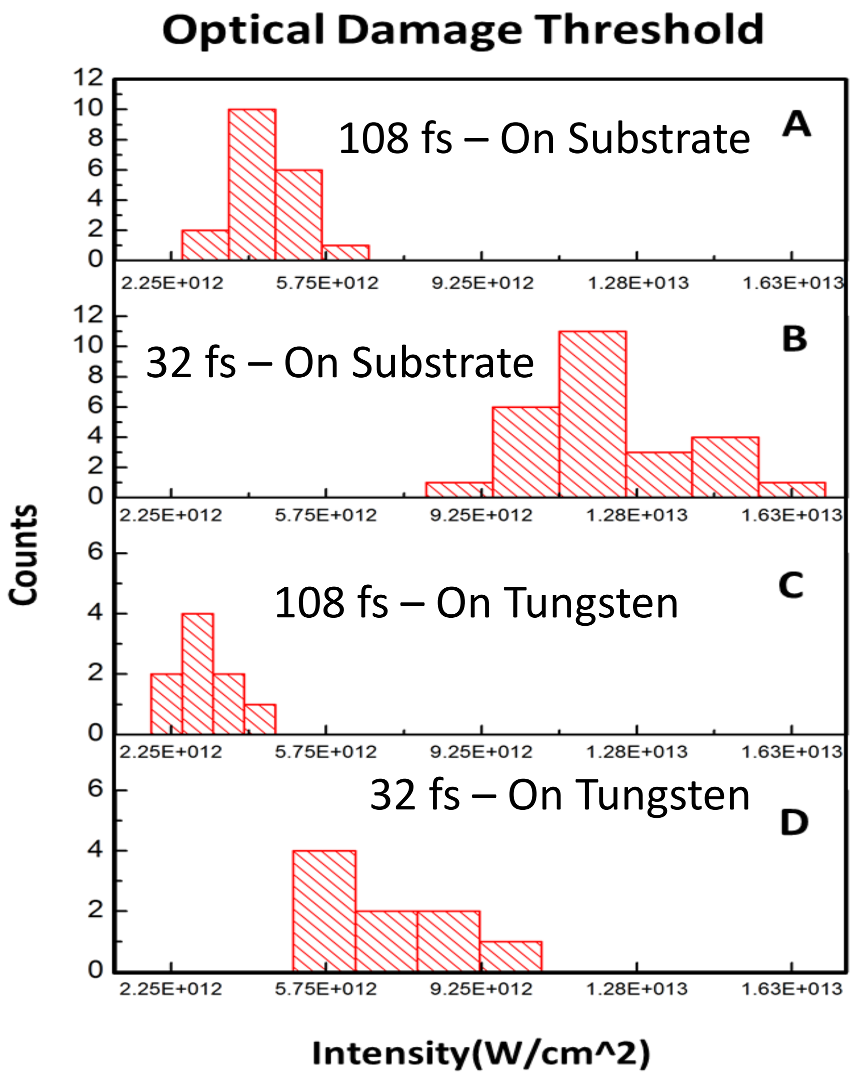
Nanowire Project

- Summers et al[1] initial experiment suggests that single-crystalline gold nanowires are damaged at very high intensities.
- Expand initial experiment to study the effects on damage threshold of:
  - Polarization
  - Wavelength
  - Pulse duration
  - Other metals
- Requires the fabrication of single-crystalline gold nanowires

[1]Summers, A. et al. (2014). *Optics express*, *22*(4), 4235-4246.

Nanowire Results

- Adam Summers' previous research into nanowire damage thresholds used tungsten wire or silica substrate bases.
- Damaging intensities for nanowires on tungsten/silica electrodes.
- Damage threshold higher for 32 fs than 108 fs pulses.
    - 2.4 ± 0.7 times higher for nanowires on tungsten
    - 2.7 ± 0.6 times higher for nanowires on glass

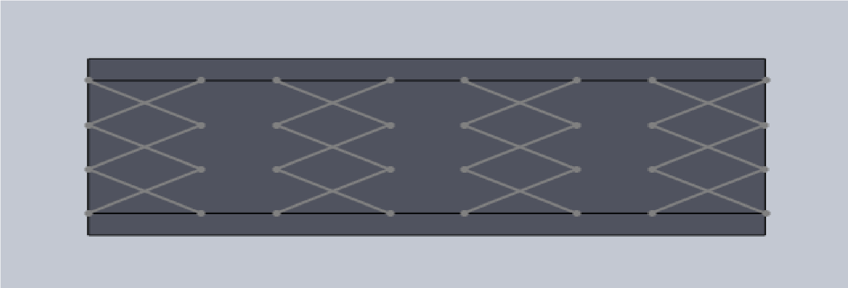


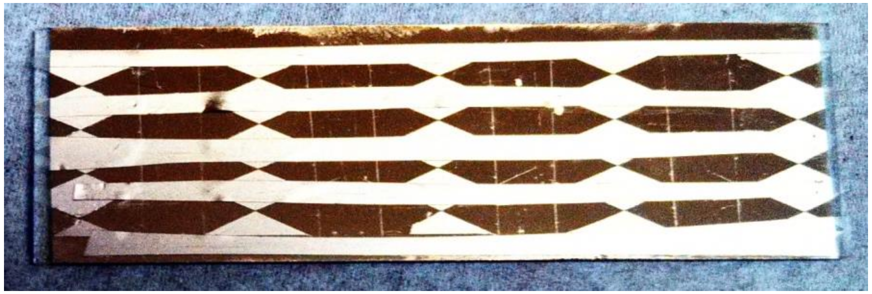
Nanowire Objectives

- Grow gold (Au) nanowires on glass slides
- Study damage threshold of Au nanowires
  - Long wavelength and few-cycle pulses
- Control polarization of electric field relative to crystal axis

Slide Fabrication

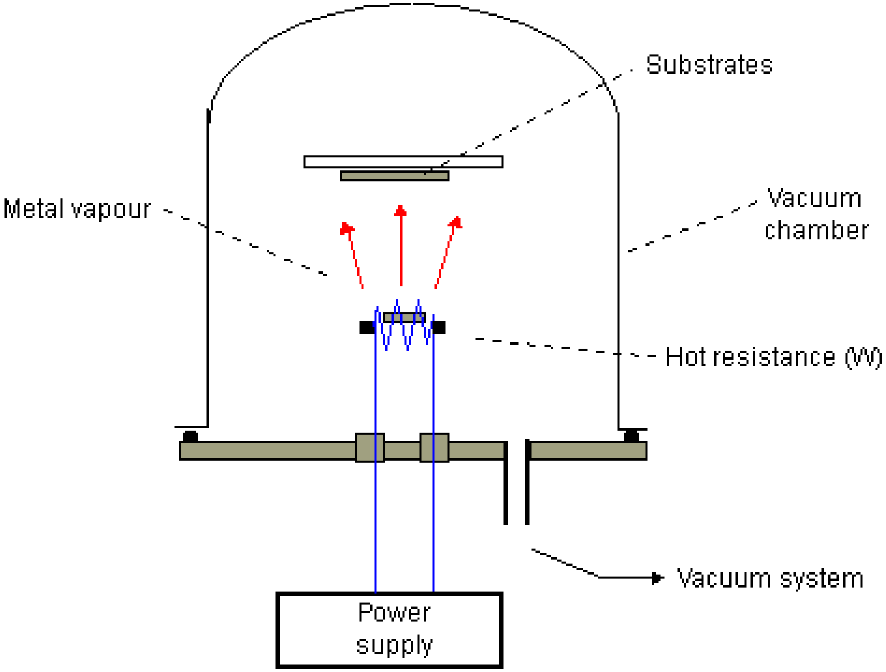
- Produced multiple gold (Au) electrodes on glass
- Made with Solidworks CAD software
- Final design provided up to 20 electrode gaps (100 µm average)





Electrode Production

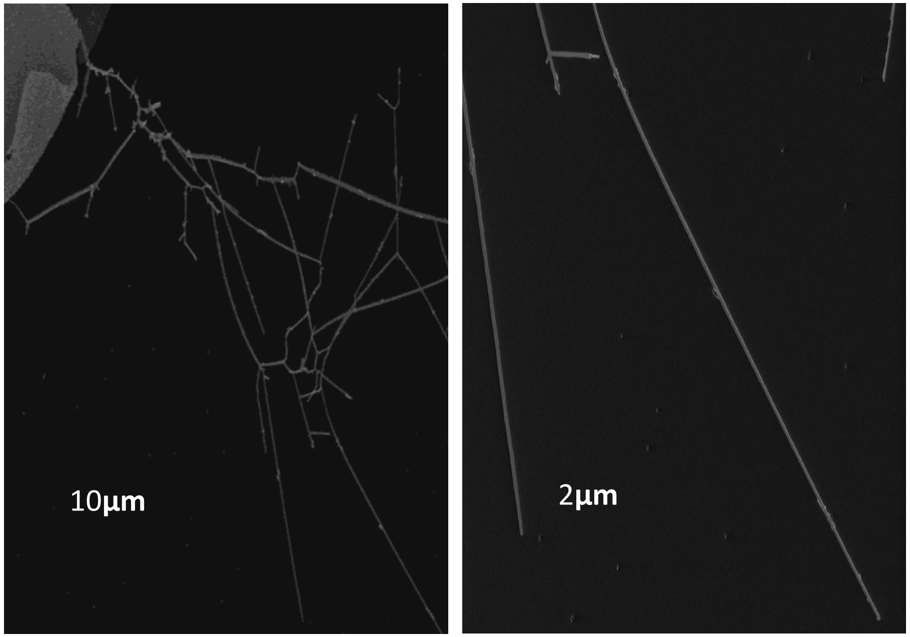
- Placed tape on methanol-cleaned slides
- Sliced tape along lines, removed pieces
- Evaporated Chromium, then Gold onto slides
    - Used a Varian VE-10 Evaporator
- Removed remaining tape to reveal electrode gaps



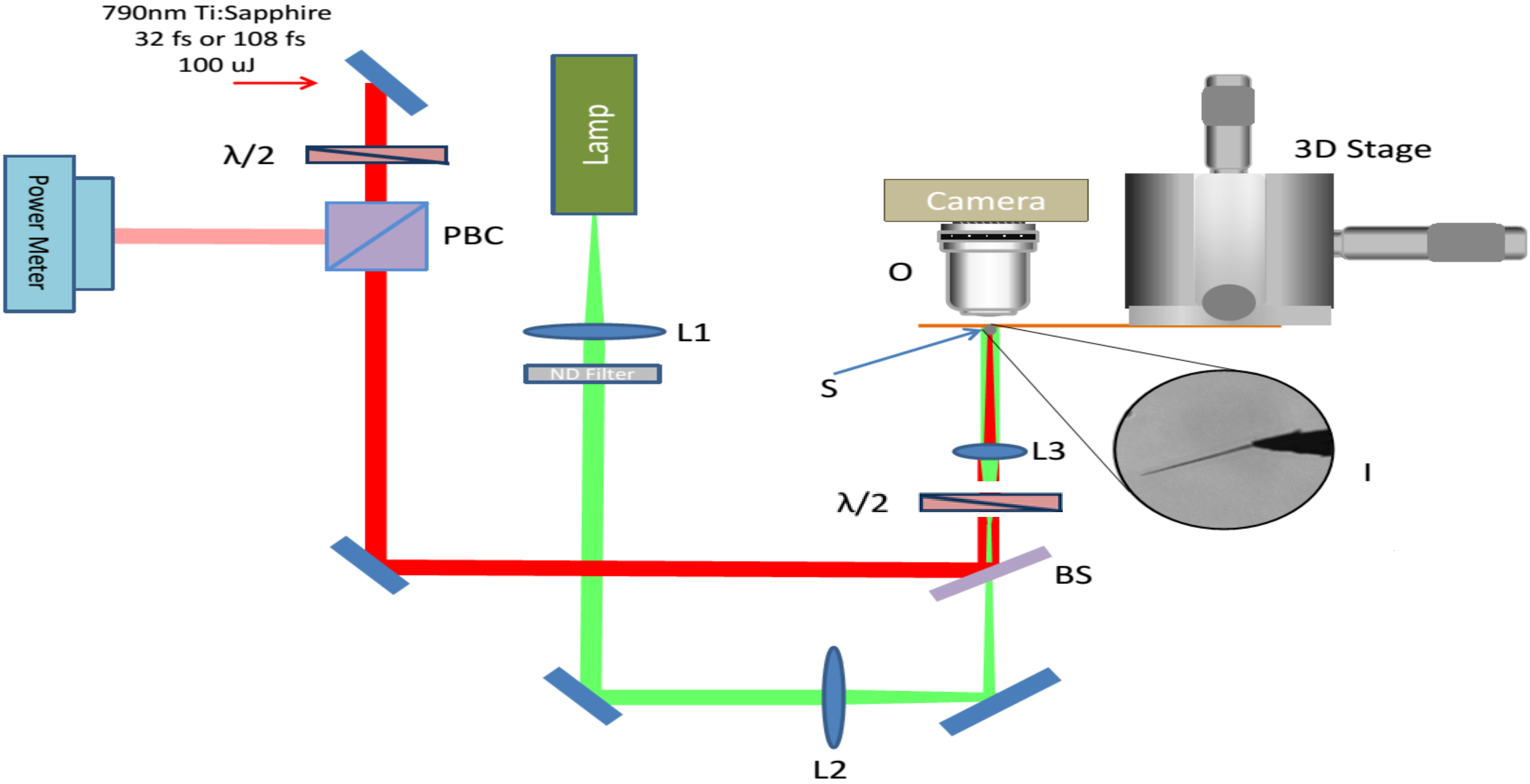
Growing Nanowires

- Ideal product: single-crystalline Au nanowires
- Group of nanowires (left) and single nanowire (right)

- Experimental Product: dense branches of nanowires, not likely single-crystalline



Nanowire Experimental Setup



Conclusion

Axicon Project:

- Successfully generated a Bessel beam and coupled into many hollow core fibers.
- Completely characterized Bessel beam by analyzing 2D slices and fitting slices to our equations by varying coefficient values.
- Not able to show an increase in the transmission efficiency (but we got close).

Nanowire Project:

- Made a useful design for making electrodes on slides and produced about one dozen slides.
- Not able to produce many high-quality gold nanowires.
- Not able to take any data varying polarization, wavelength and pulse duration.

Acknowledgements

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- Thank you to those who helped me with these projects: Joshua Nelson, Adam Summers, Dr. Carlos Trallero, Xiaoming Ren, Stefan Zigo and Dr. Bret Flanders.

- References:

- Summers, A. M., Ramm, A. S., Paneru, G., Kling, M. F., Flanders, B. N., & Trallero-Herrero, C. A. (2014). Optical damage threshold of Au nanowires in strong femtosecond laser fields. *Optics express*, *22*(4), 4235-4246.
- Kling, N. *Controlling the dynamics of electrons and nuclei in ultrafast strong laser fields* (Doctoral dissertation) Retrieved from K-State Research Exchange. <http://hdl.handle.net/2097/16821>
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