KrF Laser Drivers for Inertial Fusion Energy

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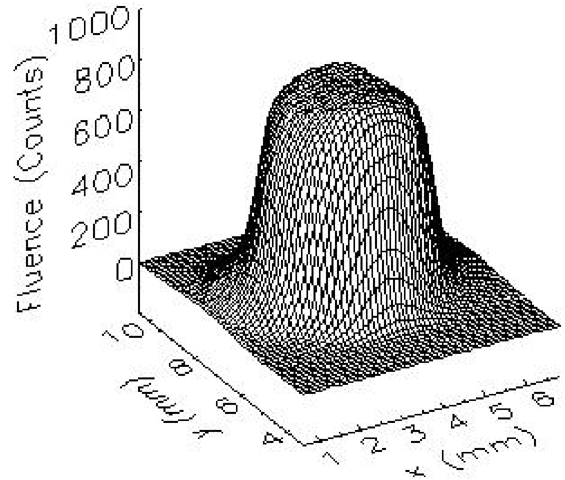
Overview

- Overview
- Advantages of KrF Lasers
- IFE requirements for KrF laser drivers
  - Efficiency
  - Durability
  - Cost
- Laser physics and technology
- Developments on Electra
  - Efficiency
  - Durability
  - Cost
- Summary

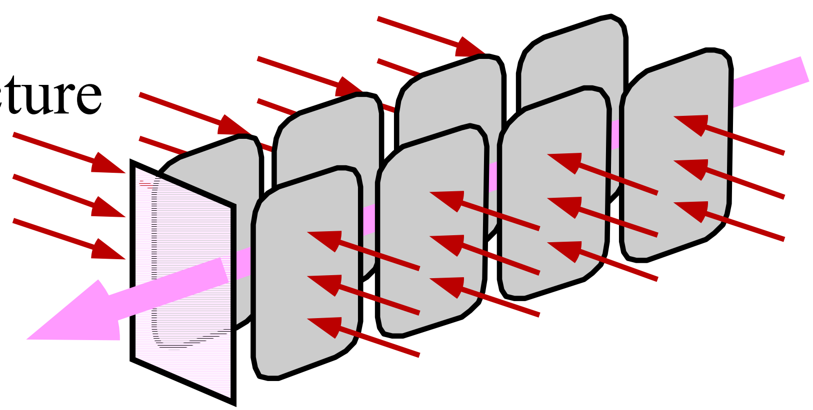
Advantages of KrF Lasers

1. Demonstrated spatial uniformity minimizes seed and growth of hydrodynamic instabilities.



2. Shortest wavelength (1/4 μm) maximizes absorption and rocket efficiencies; minimizes risk from laser plasma instabilities.

3. Electron beam pumped architecture is scalable to large systems.

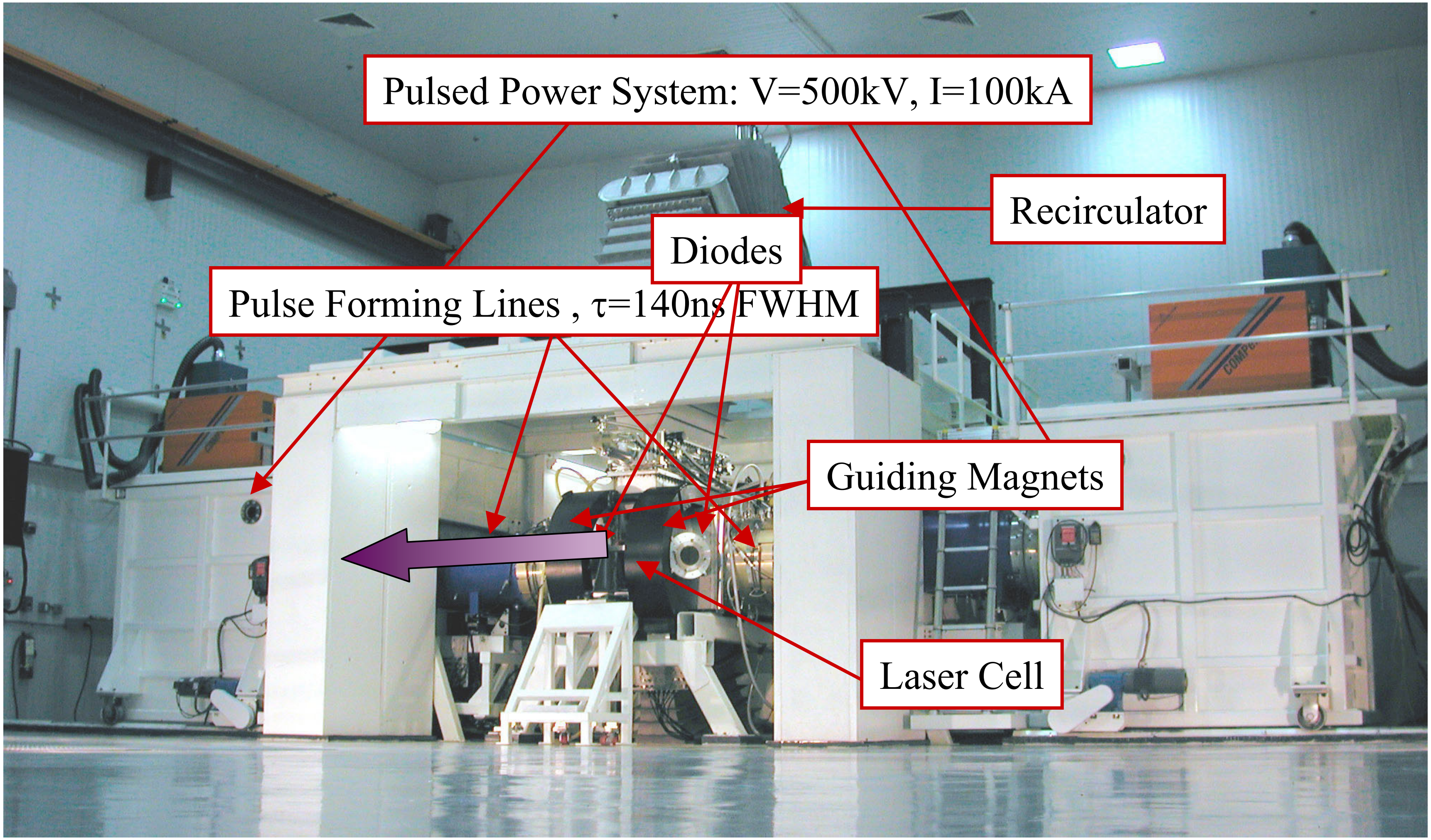


Requirements for Laser IFE Driver

Laser IFE Requirements[a]			
Parameter	**IFE Requirement**	**Electra Goals[b]**	**NIKE Results[c]**
Rep-Rate (Hz)	5 – 7	5	0.0005
Beam Line Laser Energy (J)	30k – 60k	400-700	5k
Cost of pulsed power ($/J)	5 – 10	5 – 10	N/A
Cost of entire laser ($/J)	225	N/A	N/A
System efficiency (%)	6 – 7	7	1.4
Durability (shots)	3 x 10^8	10^5	200

a. Taken from Sombrero studies: see, for example, Svaitoslavsky, I. N., *et. al.*, Fusion Technology **21**, 1470 (1992).
b. Cost and efficiency goals are based on combinations of the individual component costs and efficiencies, respectively.
c. NIKE was designed to study target physics. Electra is designed to develop the technology needed for IFE.

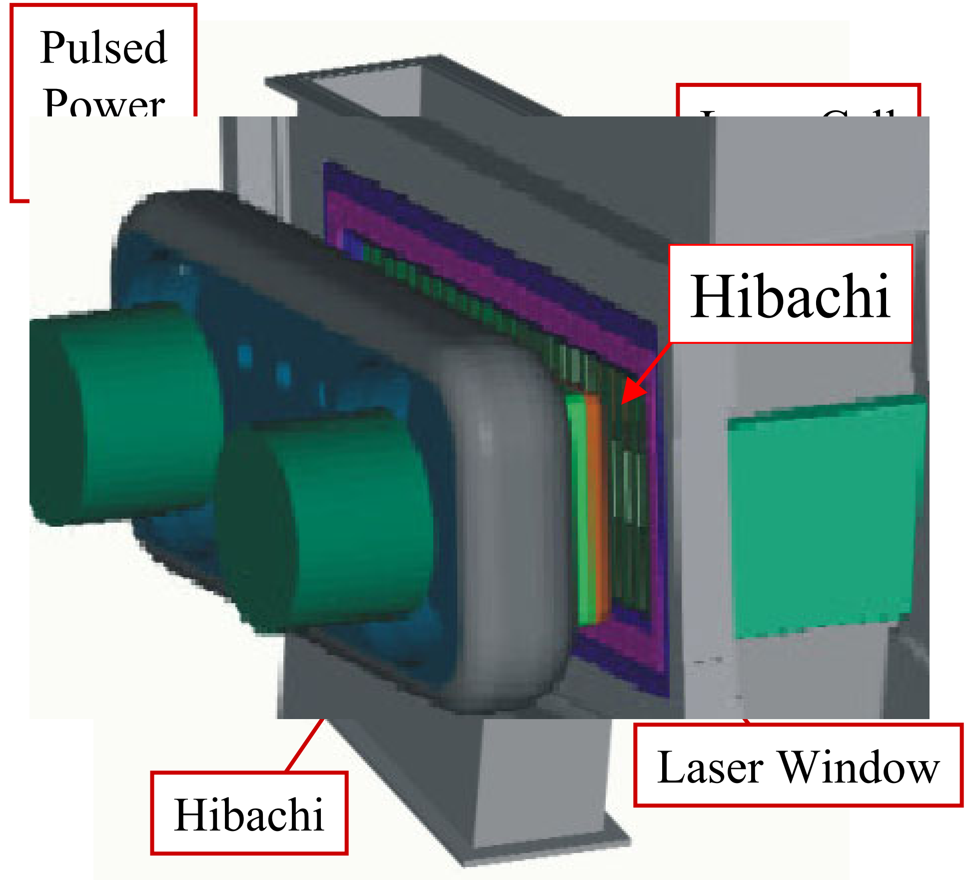
What is Electra?



Electra is a repetitively pulsed, e-beam pumped, KrF laser that is being used to develop the laser driver technology for Inertial Fusion Energy.

Primary Components of a KrF Laser

- KrF lasers are a particular type of excimer lasers
- Excimer lasers are rare-gas halide lasers emitting in the ultraviolet, that operate via the electronic transitions of molecules.
- Electra uses an $Ar/Kr/F_2$ laser gas mixture and emits at a wavelength of 248nm.



E-Beam Pumping Leads to Excitation and Ionization Reactions

The dominant formation reactions are:

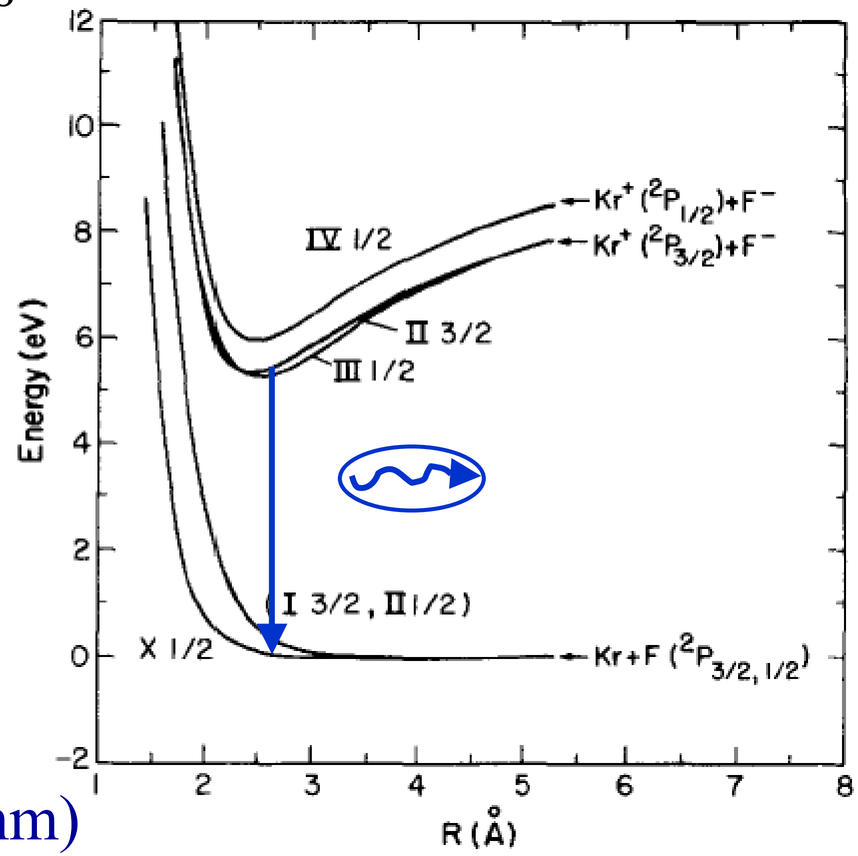
$Kr^* + F_2 \rightarrow KrF^* + F$

$ArF^* + Kr \rightarrow KrF^* + Ar$

$Kr^+ + F^- + M \rightarrow KrF^* + M$

Emission occurs when:

$KrF^* + h\nu \rightarrow Kr + F + 2h\nu$ (248nm)



Electronic States of KrF

Figure taken from P. J. Hay and T. H. Dunning, J. Chem. Phys. **66**, 1306 (1977).

Requirements for Laser IFE Driver

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System Efficiency (%)

- Pulse power efficiency, η_{pp} – conversion of wall plug energy to e-beam energy (flat-top)
- E-beam deposition efficiency, η_{dep} – transport of e-beam energy to laser gas
- **Intrinsic efficiency, η_{int} – conversion of e-beam energy to laser energy**
- Optical path efficiency, η_{opt} – transport of laser energy to target
- Ancillaries, η_{anc} – all the rest

$$\eta_{total} = \eta_{pp} * \eta_{dep} * \eta_{int} * \eta_{opt} * \eta_{anc}$$

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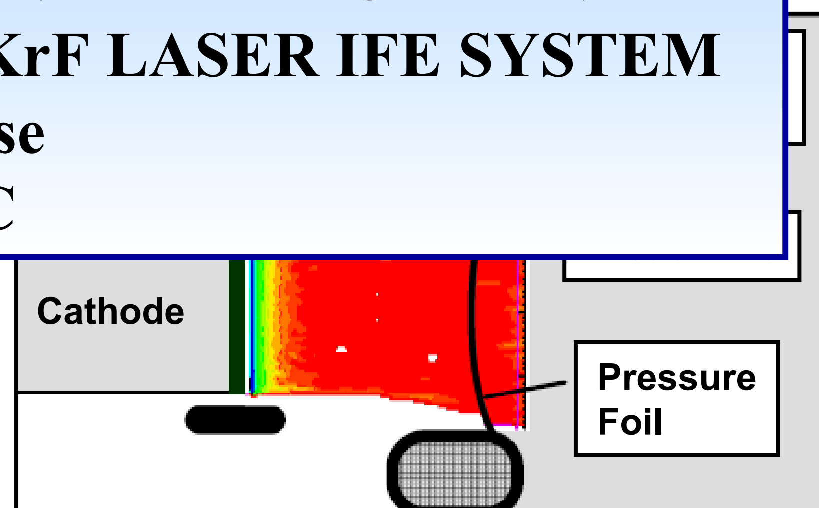
E-Beam deposition efficiency improvements

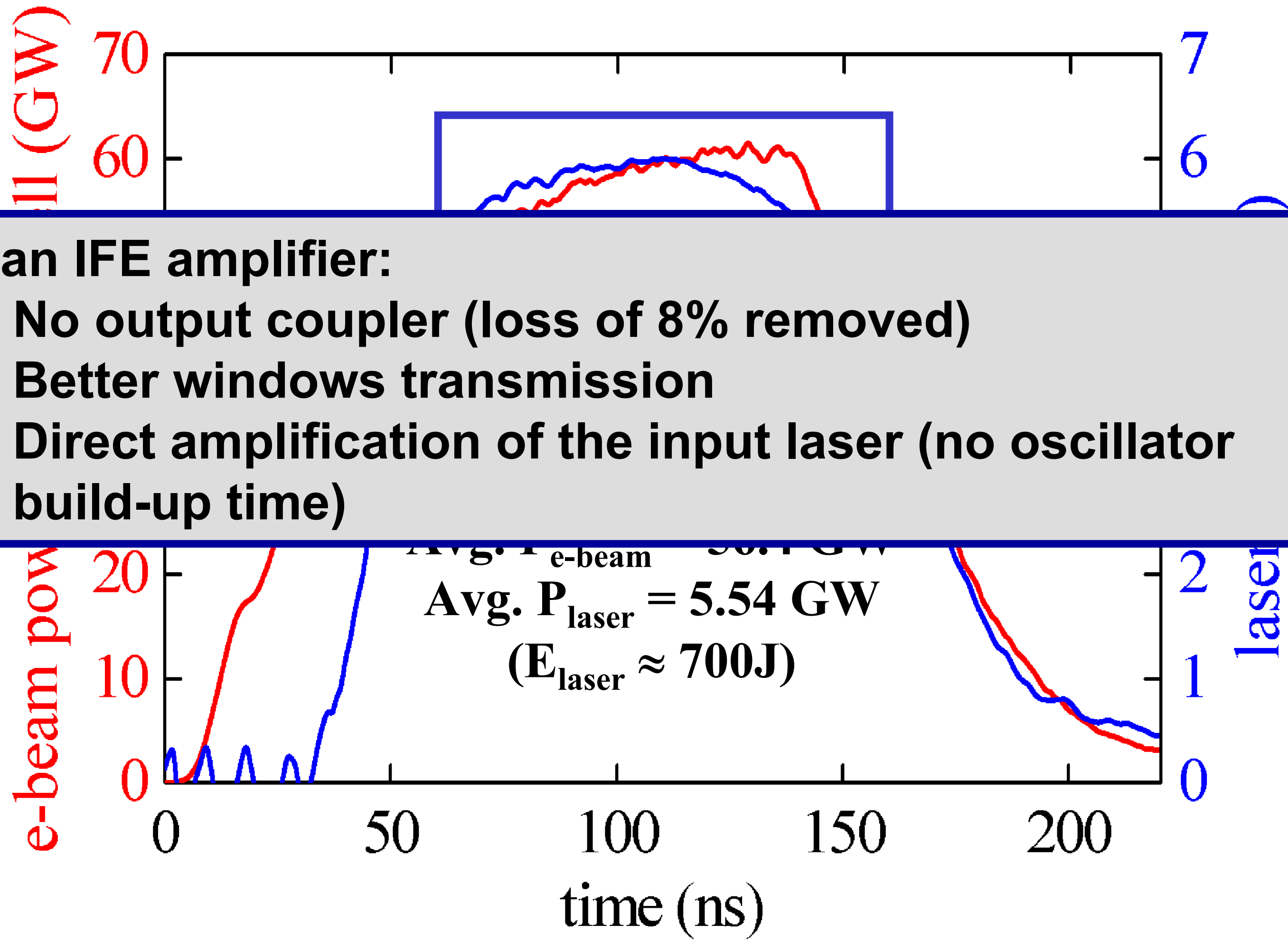
Please see
TUESDAY POSTER SESSION
1:30 - 3:30 PM
P-I-14
LARGE-AREA ELECTRON BEAM DIODE AND GAS CELL DESIGN FOR A KrF LASER IFE SYSTEM
D. Rose
MRC

- η_{dep} increased from 35% to 75%
- Agrees with LSP models by MRC
- Expect $\eta_{dep} \approx$ 80% @ 800 keV with 1 mil SS foils (full scale system)



E-beam modeling with LSP
D. Rose, MRC Albuquerque

Electra has achieved 700J per shot and an intrinsic efficiency of 9.8% as an oscillator. We expect > 12% as an amplifier



As an IFE amplifier:

- No output coupler (loss of 8% removed)
- Better windows transmission
- Direct amplification of the input laser (no oscillator build-up time)

We anticipate an IFE system efficiency of 7.4%

With:

- New pulsed power design
- Proper hibachi design
- Patterning cathode into strips to miss hibachi ribs
- Choosing pressure foils with good e-beam transmission properties
- By optimizing gas mixture

Pulsed Power design	**85%**
Hibachi/Cathode design (800keV with 1mil SS)	**80%**
KrF intrinsic efficiency	**12%**
Optical train to target	**95%**
Ancillaries	**95%**
Total	**7.4%**

Requirements for Laser IFE Driver

Durability

For an IFE system, the technological challenges include developing durable cathodes, pressure foils, laser windows and coatings.

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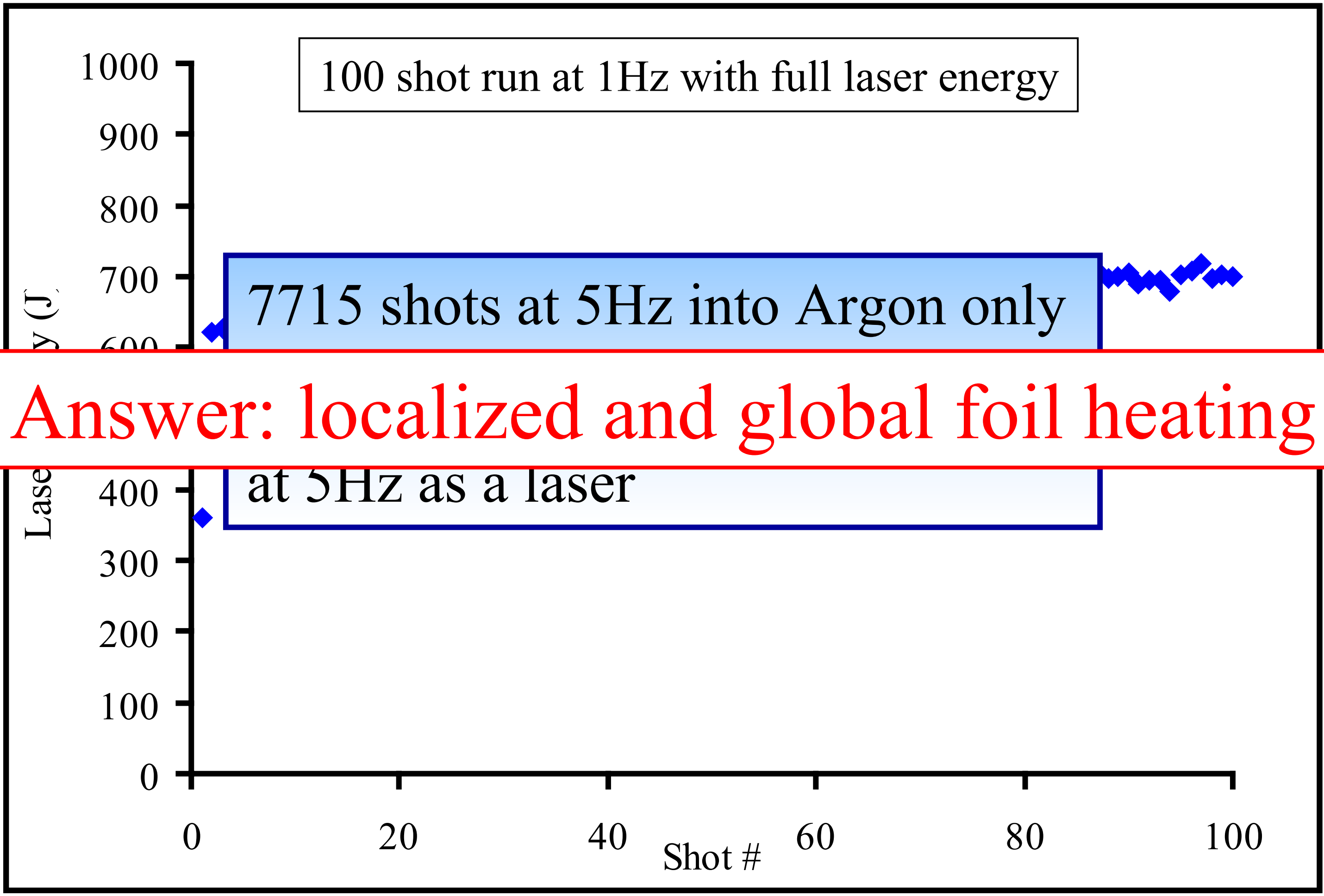
Durability Summary

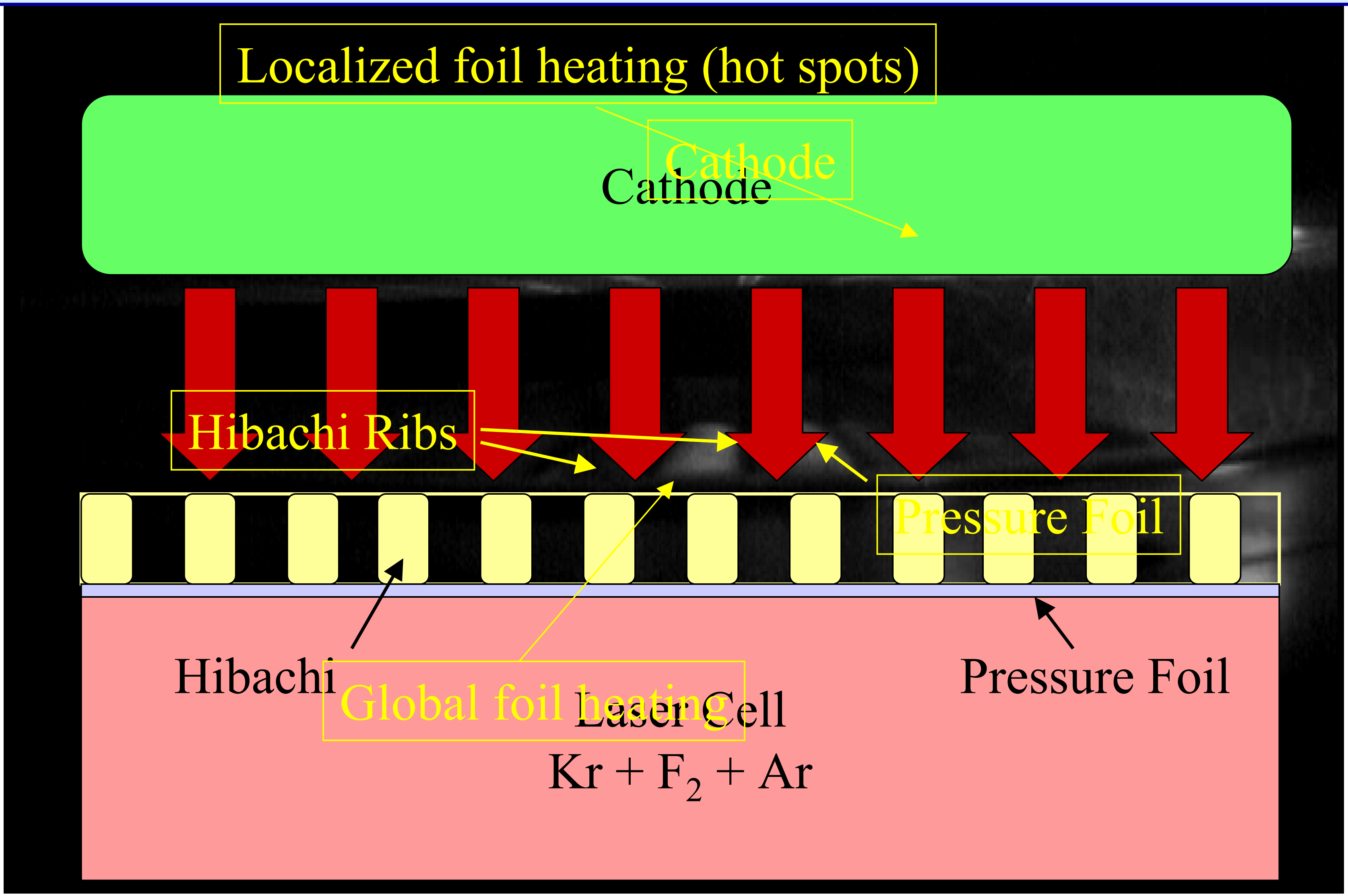


7715 shots at 5Hz into Argon only

at 5Hz as a laser

Answer: localized and global foil heating

Foil Heating



Methods for Reducing Global Foil Temperature

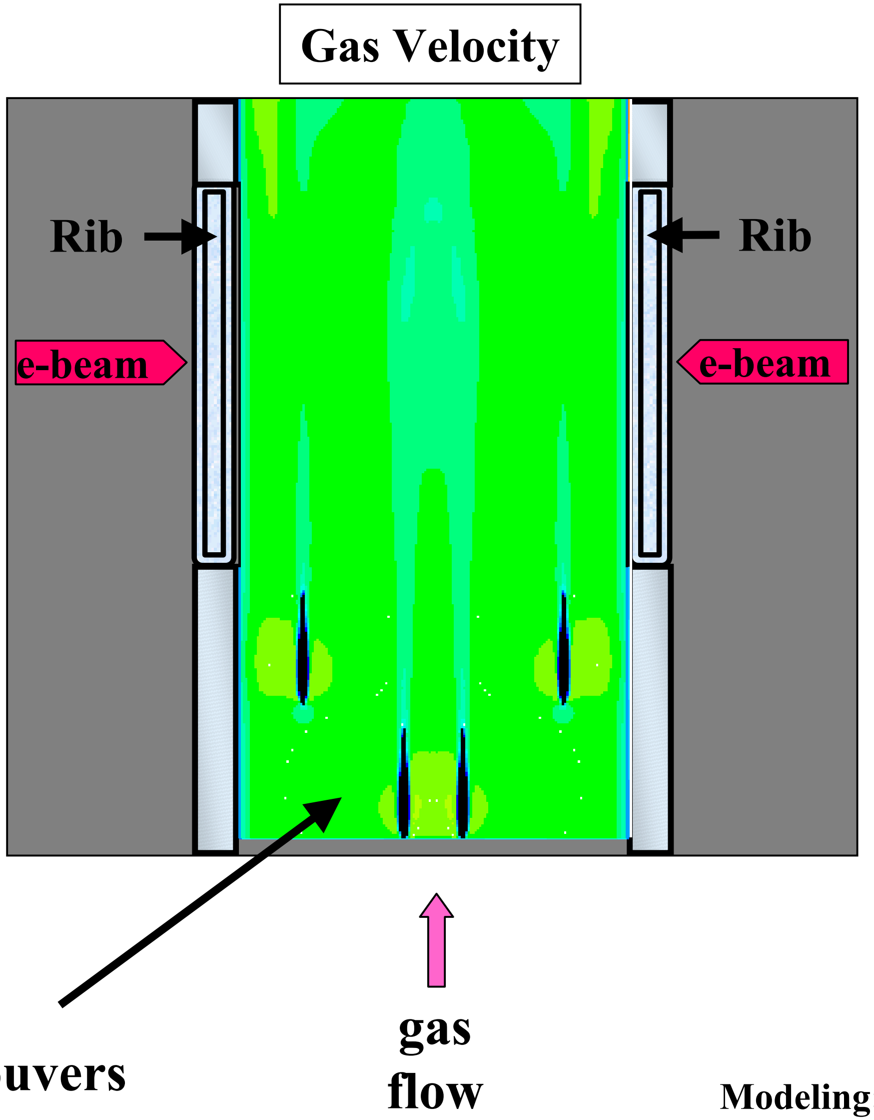
1. Gas cooling of the pressure foils, i.e., louvers

Please see
WEDNESDAY POSTER SESSION
1:30 - 3:30 PM
P-II-43
EXPERIMENTAL AND NUMERICAL INVESTIGATION OF MIST COOLING FOR THE ELECTRA HIBACHI
V. Novak
Georgia Institute of Technology

kept to near room temperature values

In all cases, the foil materials must be F_2 resistant

The recirculating laser gas can be used to cool the pressure foils by temporarily redirecting the gas flow with louvers



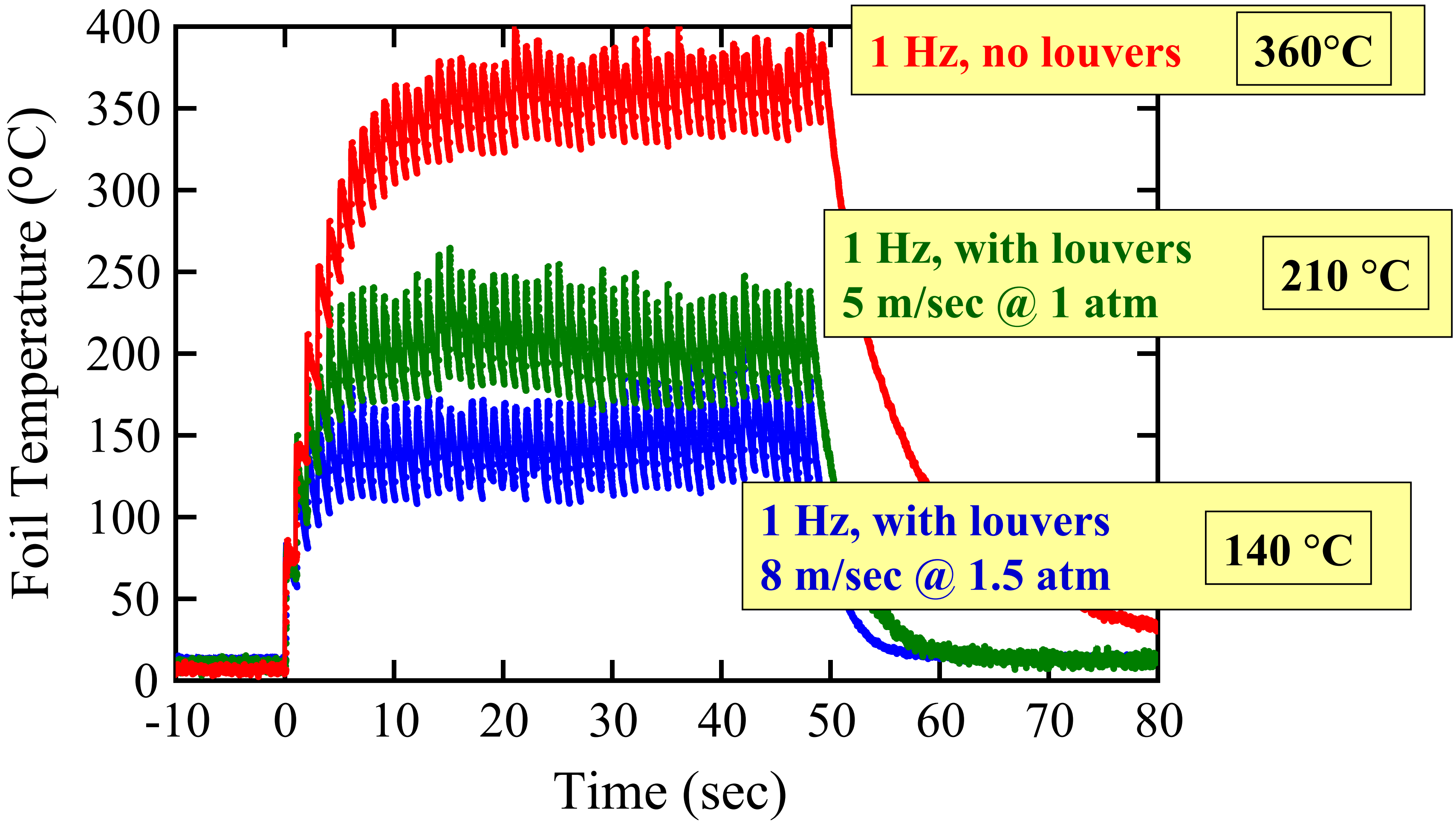
t = 200 ms

Fire E-beam

Flow is quiescent

Modeling:
A.Banka & J.Mansfield, Airflow Sciences, Inc

Experimental results show periodically deflecting the recirculating gas significantly lowers the foil temperature



We have developed a new "Ceramic Honeycomb Cathode" to mitigate localized foil heating (hot spots)

Design:

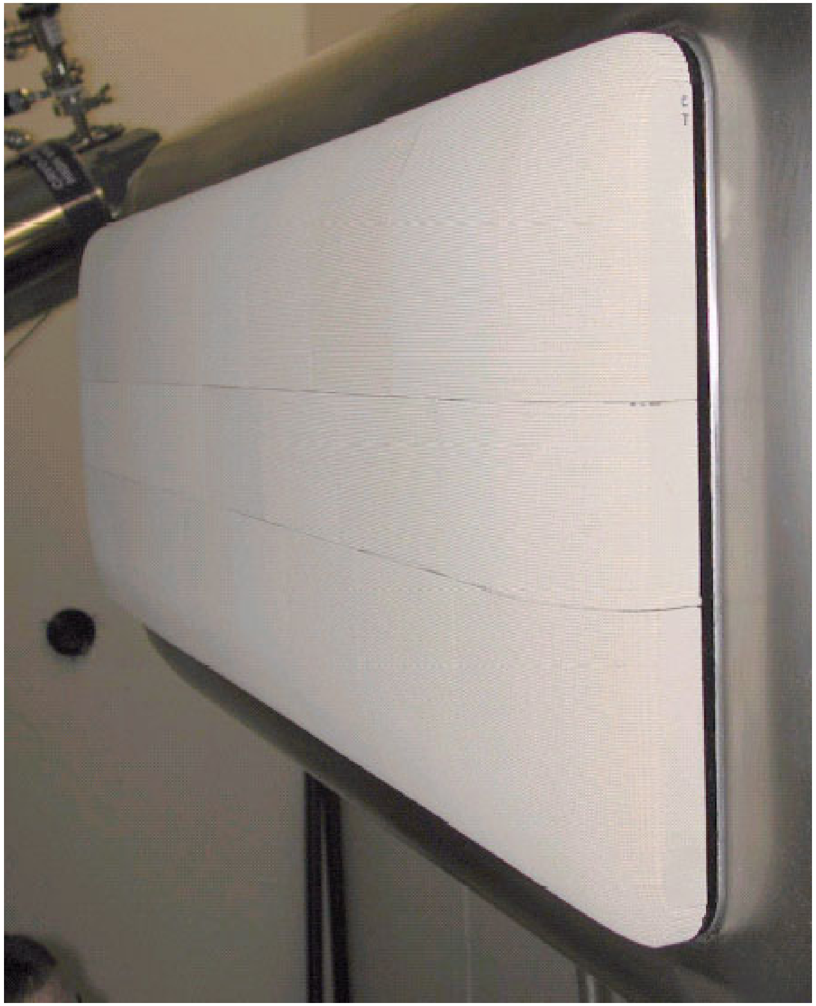
- Ceramic Honeycomb over primary emitter

Performance:

- Emits a very uniform, fast rising e-beam
- Evolves less gas into the diode
- Extends emitter and foil lifetime

Next steps are:

- Partition into strips to increase η_{dep}
- Investigate other primary emitters



See paper by M. Friedman, M. Myers, F. Hegeler, S. Swanekamp, J. Sethian, and L. Ludeking, *Appl. Phys. Lett.*, **82**, 179 (2003) for more information. Patent pending.

Requirements for Laser IFE Driver

Cost of Pulsed Power

Titan PSD has designed a new pulse power architecture that is capable of meeting the IFE efficiency, durability and cost requirements.

Parameter			
Rep-Rate (Hz)			
Beam Line Laser Energy (J)	30k – 60k	400-700	5k
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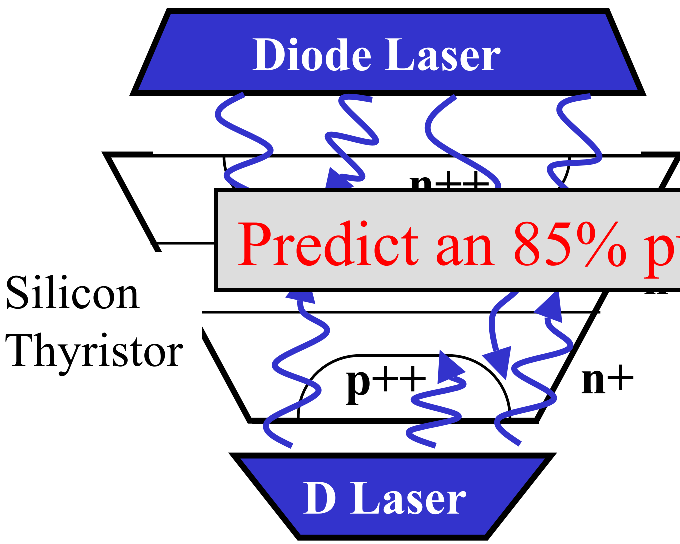
Laser Gated and Pumped Thyristor Switches

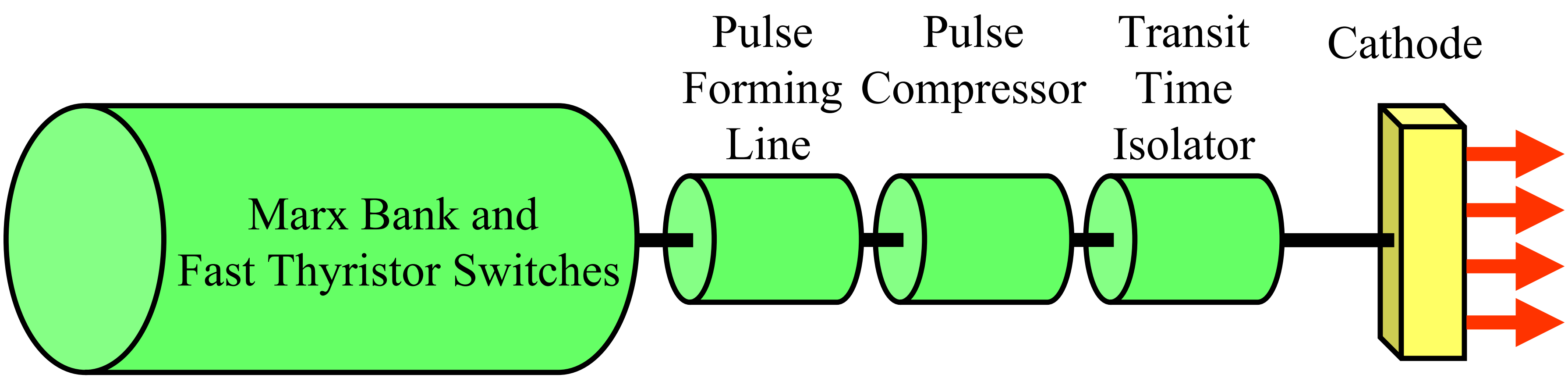


CONCEPT:

- Flood entire thyristor with photons
  - •ultra fast switching times (< 100 nsec)
  - •continuous laser pumping reduces losses

Predict an 85% pulsed power efficiency, η_{pp}, at $8.50/J

- Prototypes have being tested at 5Hz and full voltage for more than 10^6 shots
- Currently configuring them for a Marx bank application



Summary

Laser IFE Requirements[a]			
Parameter	**IFE Requirement**	**Electra Goals[b]**	**Electra Results[b]**
Rep-Rate (Hz)	5 – 7	5	5
Beam Line Laser Energy (J)	30k – 60k	400-700	700
Cost of pulsed power ($/J)	5 – 10	5 – 10	8.50
Cost of entire laser ($/J)	225	N/A	N/A
System efficiency (%)	6 – 7	7	7.4
Durability (shots)	3×10^8	10^5	10^3

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Durability is still an issue, but significant progress is being made