# Faraday Isolators and Electro-Optic Modulators for Advanced LIGO

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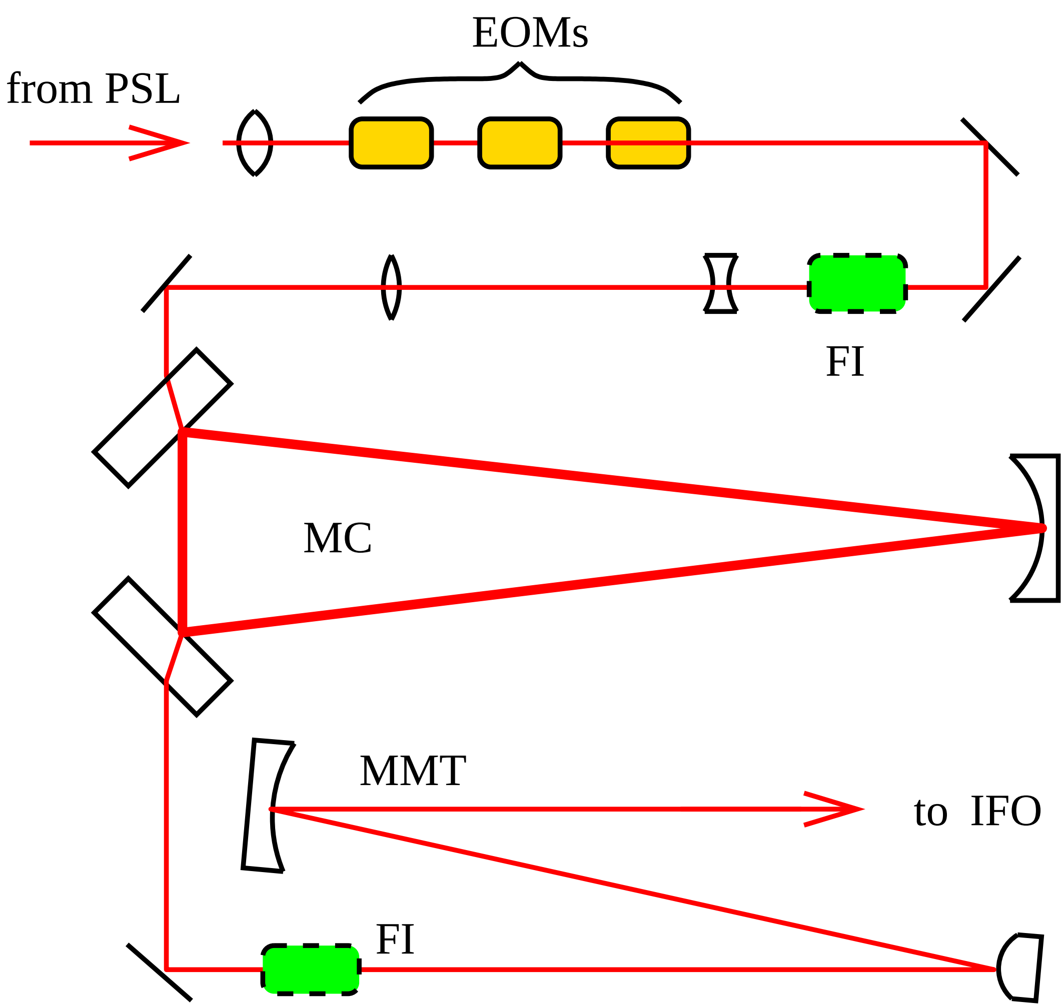
# Outline

- UF—IO
- UF’s task for Adv. LIGO
- Thermal Lenses
- Analysis scheme
- Compensation scheme
- Experimental setup
- Results
- EOM
- Summary

# Input Optics




4 Functions:

- Phase modulation
- Optical Isolation
- Mode cleaning
- Mode Matching

# TASK

**To provide LIGO with active optical crystals that ...**

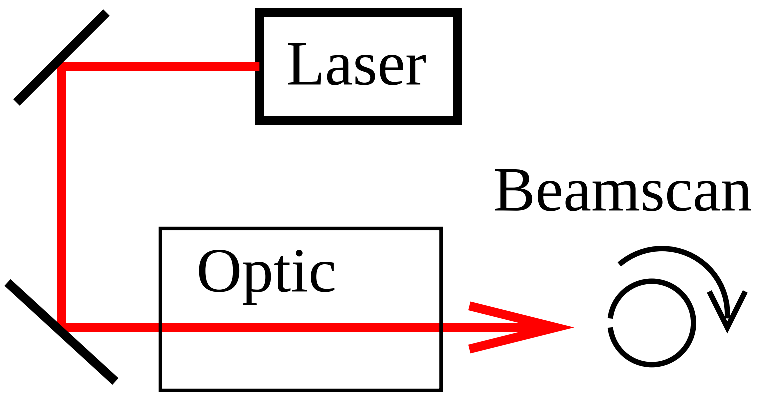
- **can handle 180 W**
- **have a well known thermal lens**
- **do not degrade the spatial TEM00-mode by more than 5% .**
- **have a small birefringence.**

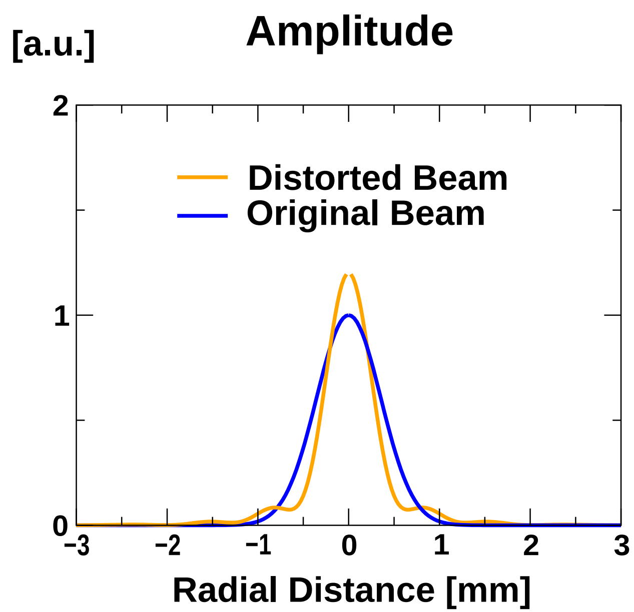
**These are ...**

- **Faraday Isolators that have**
  - **an isolation of around 40dB**
- **Electro Optical Modulators with**
  - **a modulation index of 0.5 (max.)**
  - **a small (and stable) RFAM**
  - **an amplitude stability** $10^{-8}/\sqrt{Hz}$

# Thermal Lensing

## Thermal lensing changes the beam profile:



# THERMAL LENSING ANALYSIS

## All contributions:

1. **Temperature dependent Index of Refraction**

$$\Delta OPL_{th}(r) = \frac{dn}{dT} L \Delta T(r)$$

2. **Photoelastic Effect**

$$\Delta OPL_{PE}(r) \approx -\frac{n^3}{2} \rho_{12} \gamma L \Delta T(r)$$

3. **Thermal Expansion**

$$\Delta OPL_{TE}(r) \approx 2\gamma n w \Delta T(r)$$

**In most cases:**

$$|\Delta OPL_{th}(r)| > |\Delta OPL_{PE}(r)| > |\Delta OPL_{TE}(r)|$$

$\gamma$: **thermal expansion coefficient**
$\rho_{12}$: **photoelastic coefficient**

**Mansell et al, Evaluating the effect of tranmissive optic thermal lensing on laser beam quality with a Shack-Hartmann wave-front sensor.Äpp. Optics, 40 (366-374), 2001.**

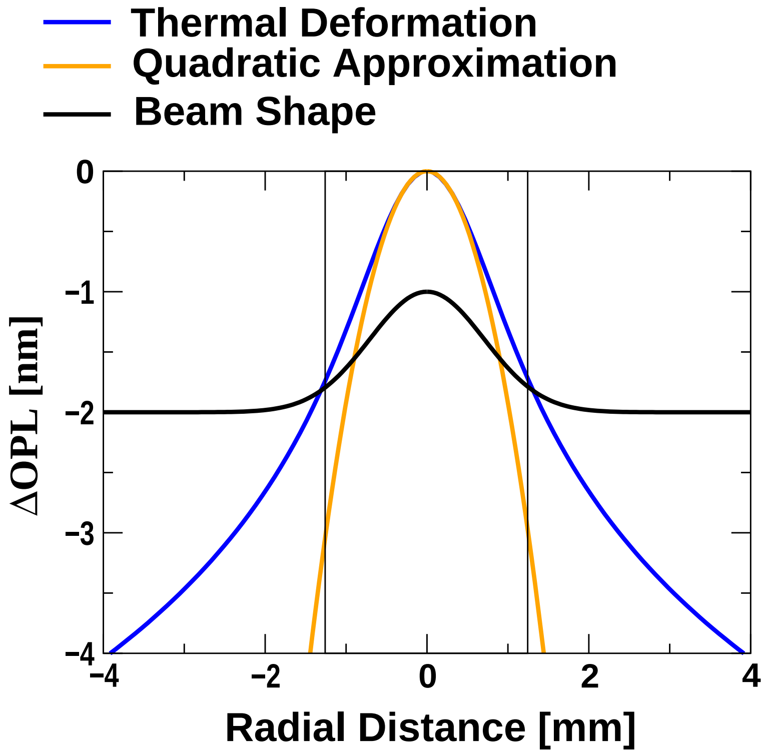
# THERMAL LENSING ANALYSIS

## Use cylindrical symmetry and long optic approximation:

$$\nabla^2 T(r) = -\frac{I(r)}{k}$$

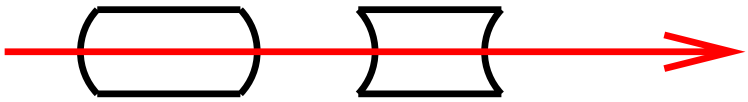
$$\Rightarrow \Delta T(r) = \frac{\alpha P}{4\pi k} \sum_{j=1}^{\infty} \frac{(-1)^j \left(\frac{2r^2}{w^2}\right)^j}{j\,j!}$$

$$\Delta OPL(r) = \frac{dn}{dT} L \Delta T(r)$$



# Thermal Compensation

**The idea:**



**Add a second media with a negative $\frac{dn}{dT}$.**

$$\Delta OPL(r) = \Delta OPL_1(r) + \Delta OPL_2(r)$$

**If**

$$\Delta OPL_1(r) = -\Delta OPL_2(r)$$

$\Rightarrow$ **No Thermal Lensing**

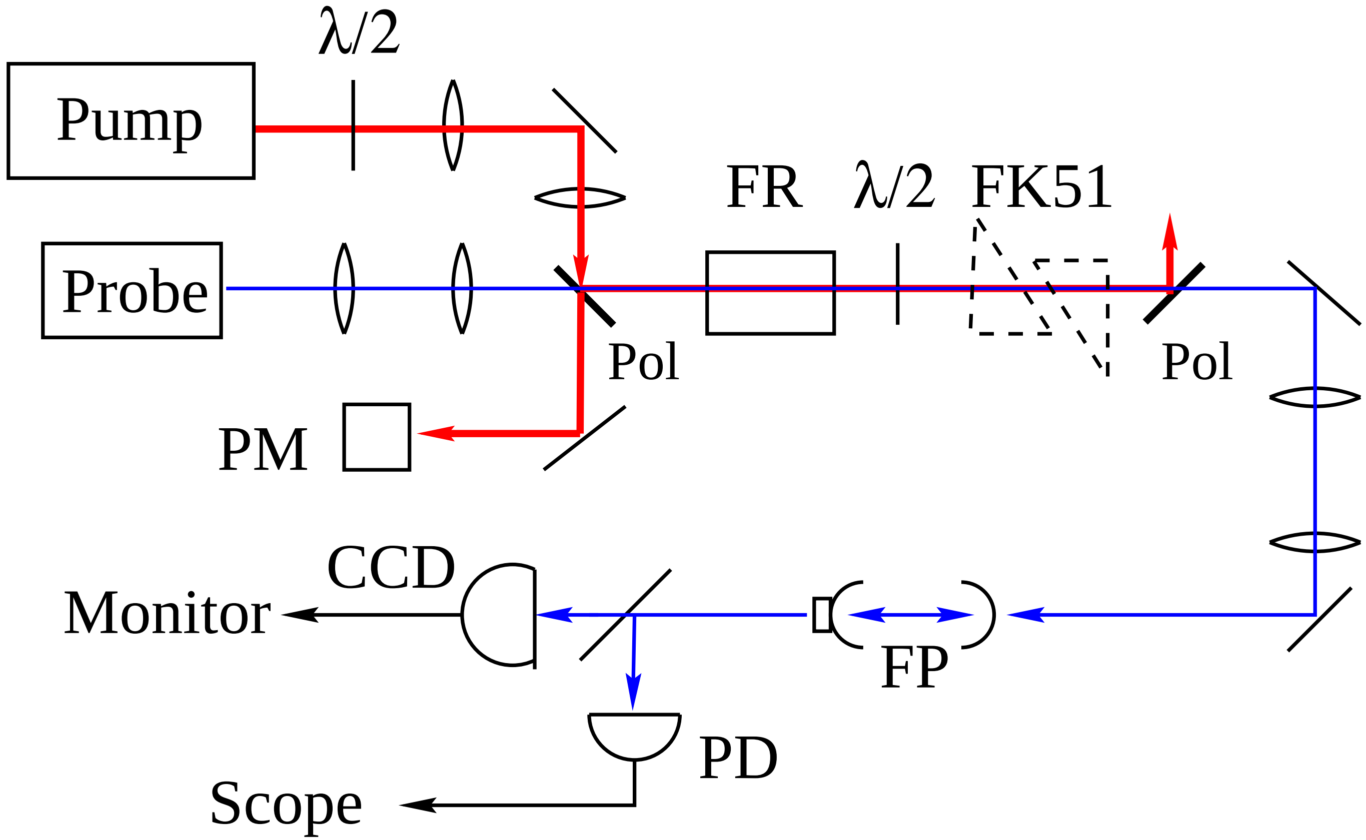
**No Beam Degradation**

**Need material with** $\frac{dn}{dT} < 0$

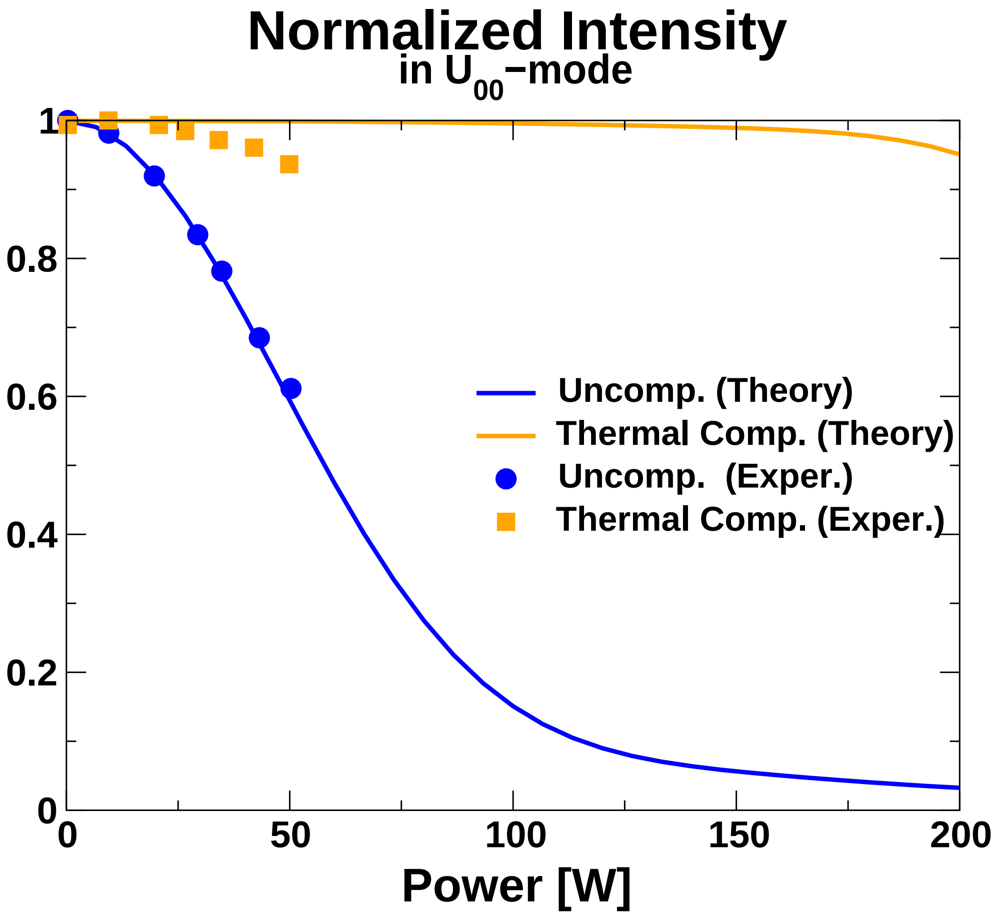
**FK51:** $\frac{dn}{dT} = -6 \cdot 10^{-6}/K$

**Ref: MacDonald et al, Reducing thermal lensing in diode-pumped laser rods. Optics Communications. 178, 15 May 2000**

# Experimental Setup



# EXPERIMENTAL RESULTS

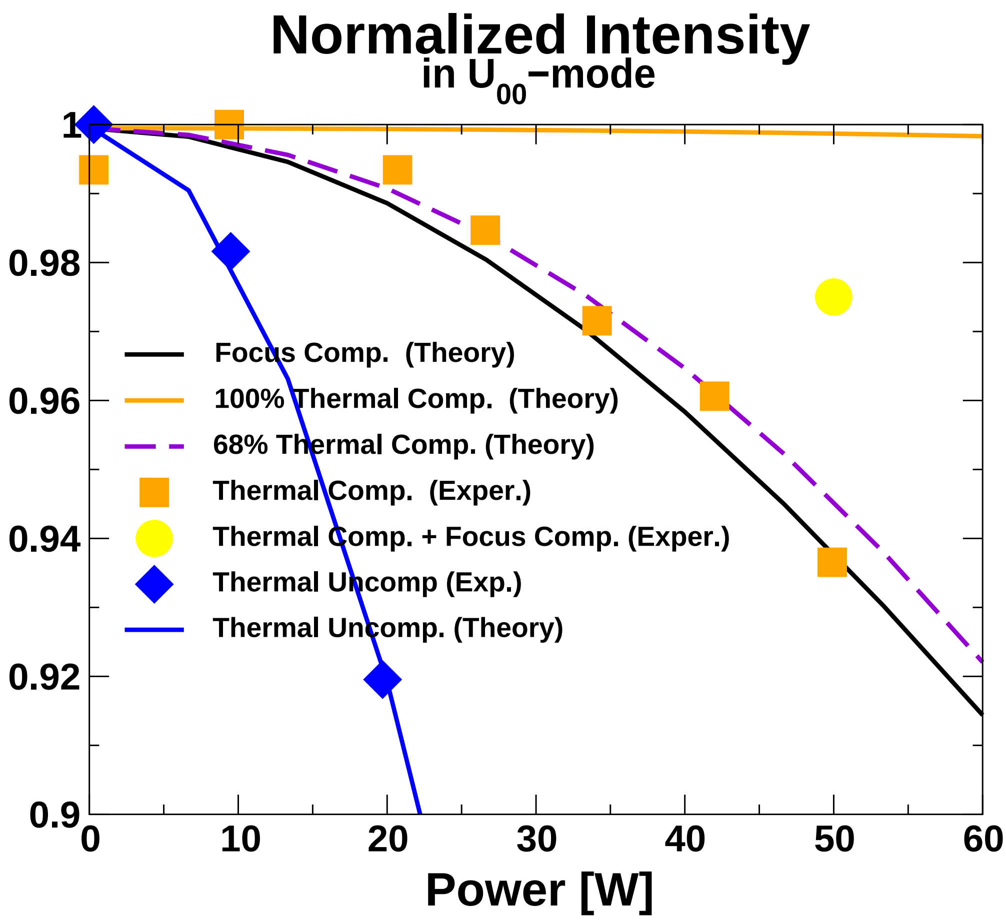



**Problem: Absorption Coefficient**

| TGG | Our | Lit. | Other Crystals |
|---|---|---|---|
| $\alpha[\mathrm{m}^{-1}]$ | 0.63 | 0.2 | 0.15-0.25 |

**Best Guess: Our Compensator prisms are to short.**

# EXPERIMENTAL RESULTS




**Measured a 97.5% mode matching efficiency for Thermal and Focus Compensation.**

**Looks like its working.**

**Remember: 50W here is 200W in a good crystal.**

# ELECTRO OPTIC MODULATORS

## LIGO I:

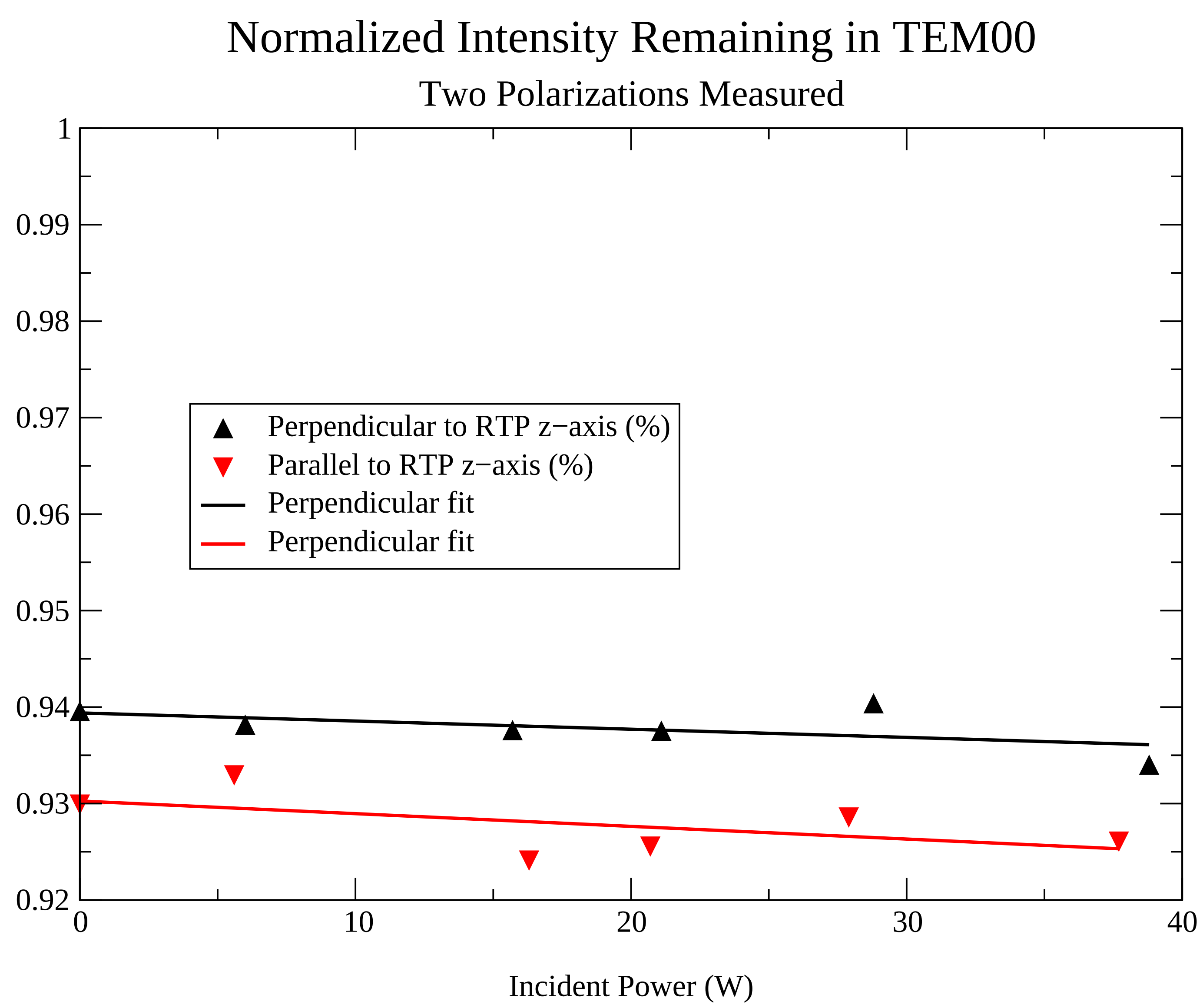
**$LiNbO_3$ resonant modulators from New Focus.**

- **Useful up to 20-30W.**
- **absorption to high**
- $dn/dT$ **very asymmetric along the two axes.**

## Advanced LIGO:

**Possible Materials: RTP, RTA**

- **low absorption (RTP** $50ppm/cm$**)**
- **Low loss tangent (RTA** $4 \cdot 10^{-4}$**)**
- **Very Low Conductivity (RTA** $3 \cdot 10^{-7}/\Omega m$**, RTP** $10^{-9}/\Omega m$**)**
- **High EO-coefficient (90% of $LiNb0_3$)**
- **Expensive**


Normalized Intensity Remaining in TEM00
Two Polarizations Measured
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0
10
20
30
40
Perpendicular to RTP z−axis (%)
Parallel to RTP z−axis (%)
Perpendicular fit
Perpendicular fit
Incident Power (W)

# SUMMARY

- Faraday Isolator results and outlook:
  1. 97.5% mode matching at 50W with bad TGG crystal using compensator design.
  2. No obvious problems with prism design so far
  3. 30dB isolation with this standard isolator
  4. IAP/UF demonstrated 45dB with dual crystal design
  5. Merge compensator and Russian dual crystal design
  6. Solve practical problems like adjust to different absorption coefficients.
- Electro Optic Modulator results and outlook:
  1. Material identified
  2. Thermal lensing and beam degradation neglegible
  3. Testing in progress