



**AFRL-ML-WP-TP-2007-534**

**CONTRA-DIRECTIONAL TWO-BEAM COUPLING FOR  
VARIABLE REAR REFLECTIVITIES IN LiNbO<sub>3</sub>:Fe  
(PREPRINT)**

**Dean R. Evans**

**Hardened Materials Branch  
Survivability and Sensor Materials Division**

**AUGUST 2006**

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\*//Signature//

DEAN R. EVANS, Ph.D.  
Agile Filters Project  
Exploratory Development  
Hardened Materials Branch

//Signature//

MARK S. FORTE, Acting Chief  
Hardened Materials Branch  
Survivability and Sensor Materials Division

//Signature//

TIM J. SCHUMACHER, Chief  
Survivability and Sensor Materials Division

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| <b>14. ABSTRACT</b><br>1. Coating the rear c-surface, we are able to produce a controlled range of rear reflectivity on a photorefractive LiNbO3 crystal.<br>2. The contra-directional two-beam coupling does not vary significantly with reduced rear reflection. This agrees with theoretical calculation<br>3. The time response of two beam coupling increases with reduced reflectivity.<br>4. Future work will produce similar work on other types of photorefractive crystals.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                            |                                                    |                                  |                                                                                                                                                           |                                                                                                                                                                                                                                                                                                            |                                                                           |  |                                  |
| <b>15. SUBJECT TERMS</b><br>Two Beam Coupling (TBC), Residual Reflection, Photorefractive Crystals                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                            |                                                    |                                  |                                                                                                                                                           |                                                                                                                                                                                                                                                                                                            |                                                                           |  |                                  |
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# Contra-directional two-beam coupling for variable rear reflectivities in $\text{LiNbO}_3\text{:Fe}$



**\*Gary Cook\*\*Mohammad Saleh, and \*\*\*Dean R. Evans\*\*\*\* Gerald Landis**

**\*Universal Technologies Corp, Dayton, OH 45432 \*\* UES, Inc. Dayton, OH 45432**

**\*\*\*\*University of Dayton Research Institute, Dayton OH**

**\*\*\*Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson Air Force Base, OH 45433**

**23 – 25 August 2006  
Sand Key, Florida**



# Outline

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- **Motivation**
- **Design and implementation**
- **Photos and reflectivity data**
- **Coupling measurements**
- **Results**



# Motivation



- Can't afford enough identical samples to explore parameter space on first cut
- "Identical" really means **identical**
- Same  $\text{Fe}^{2+}/\text{Fe}^{3+}$  ratio
- Same coating on front and same wedge angle are obviously less important, but can create difficulties in interpretation
- We need to have an experimental handle on the tradeoffs in ultimate transmission (residual reflection), speed of response, and ultimate OD



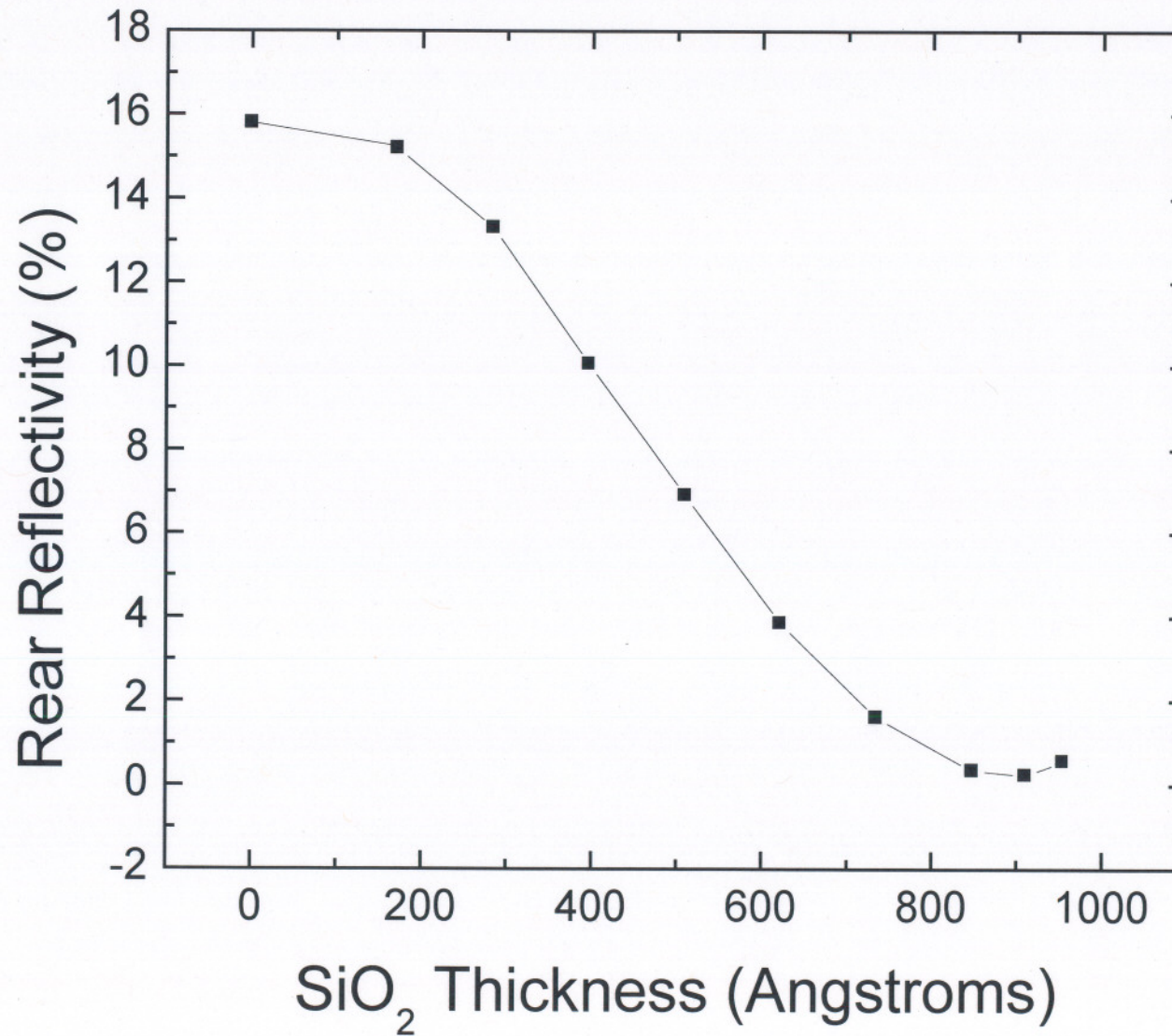
# Design and implementation of coating



- We have the ability to RF sputter deposit  $\text{SiO}_2$
- At 532nm., it is calculated that 911 Angstroms of material will be a quarter wave AR coating. We expect a cosine dependence for reflectivity on thickness as we increase from 0 (uncoated  $R=15.7\%$ ) to 911 A.
- We first put an AR coat on the front (-c) surface
- On the back surface (+c where the arrow points in the picture), we used masks to sequentially deposit 8 different thicknesses (5 min/deposition, last = 7.5min)
- The masks rested on a 5+mm thick Al plate with a hole cut for the sample to rest on the sputter deposition table
- Witness samples (Si wafer chips) showed a deposition ratio of 1.14 for Al/table
- Reflection measurements indicate front AR = 1%  $R = 1000 \text{ A}$



# Reflectivity vs. $\text{SiO}_2$ Thickness





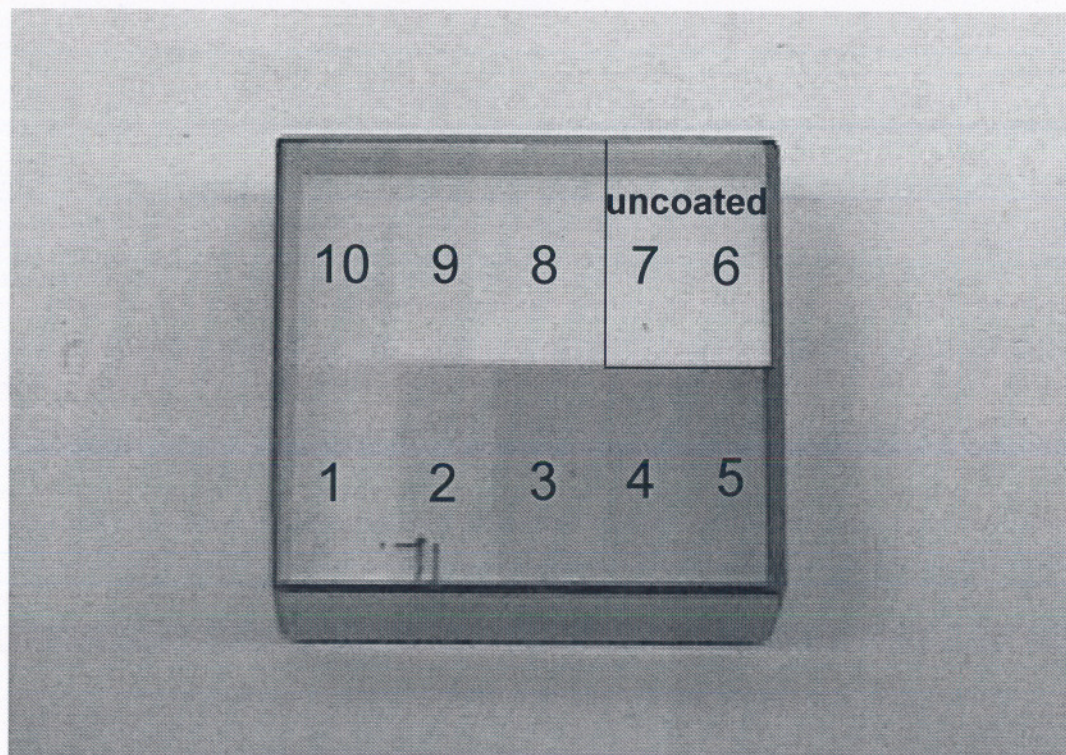
# SiO<sub>2</sub> Coating Layer Thickness



|        |     |     |     |          |     |
|--------|-----|-----|-----|----------|-----|
| c-axis | 397 | 284 | 171 | Uncoated |     |
|        | 510 | 622 | 735 | 848      | 955 |

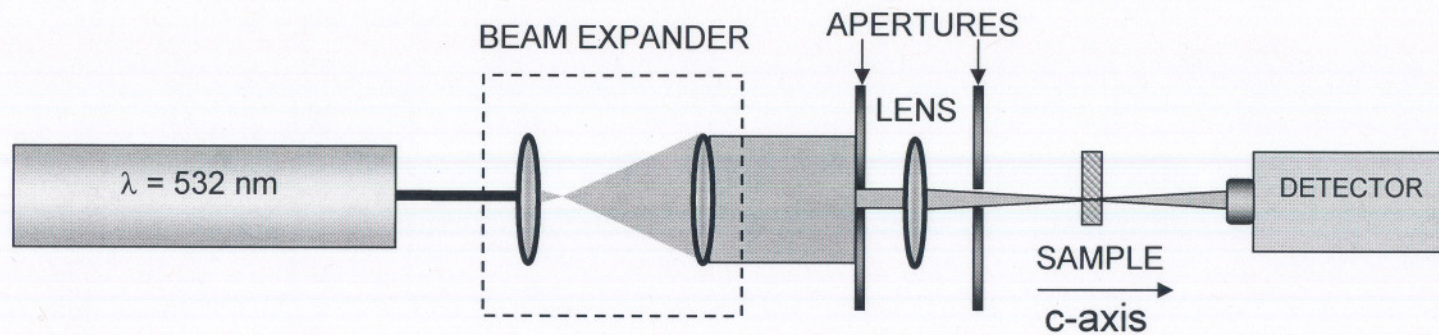


# Coated crystal





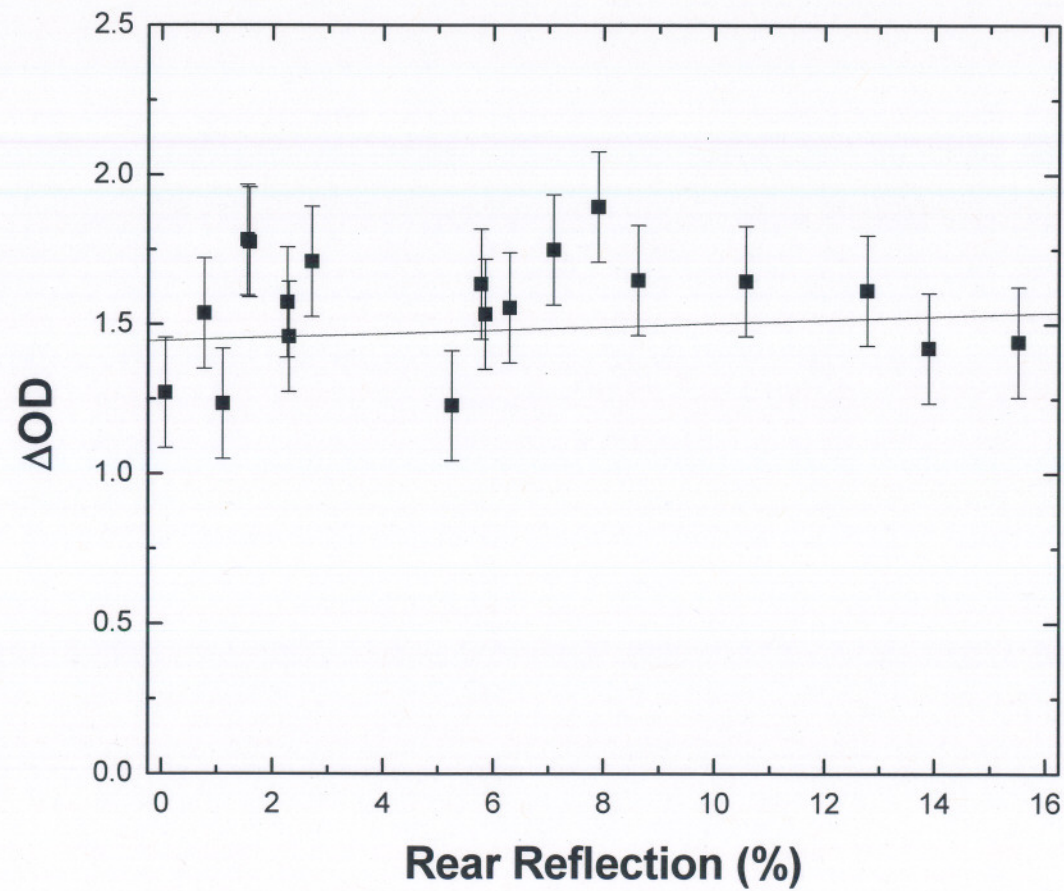
# TBC Efficiency Measurement



- TBC efficiency is measured as the change in optical density.
- Optical density =  $-\log(\text{Power}_{\text{out}} / \text{Power}_{\text{in}})$ .
- Higher TBC efficiency implies  $\text{Power}_{\text{out}}$  is smaller.
- Error sources:
  - Mask placement by hand
  - Material deposition under the mask, giving a gradient
  - Photovoltaic noise changes the steady state transmission
  - Etalon effect may have added error to the transmission (?)

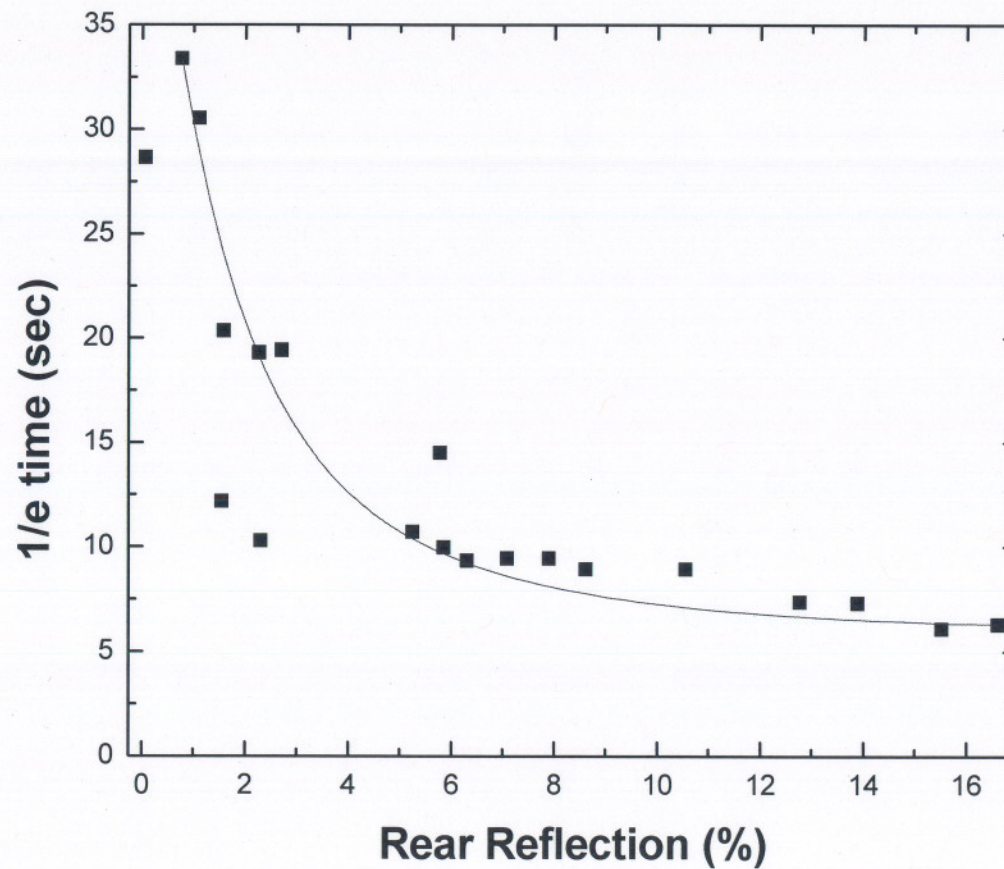


# $\Delta OD$ vs. Rear Reflectivity



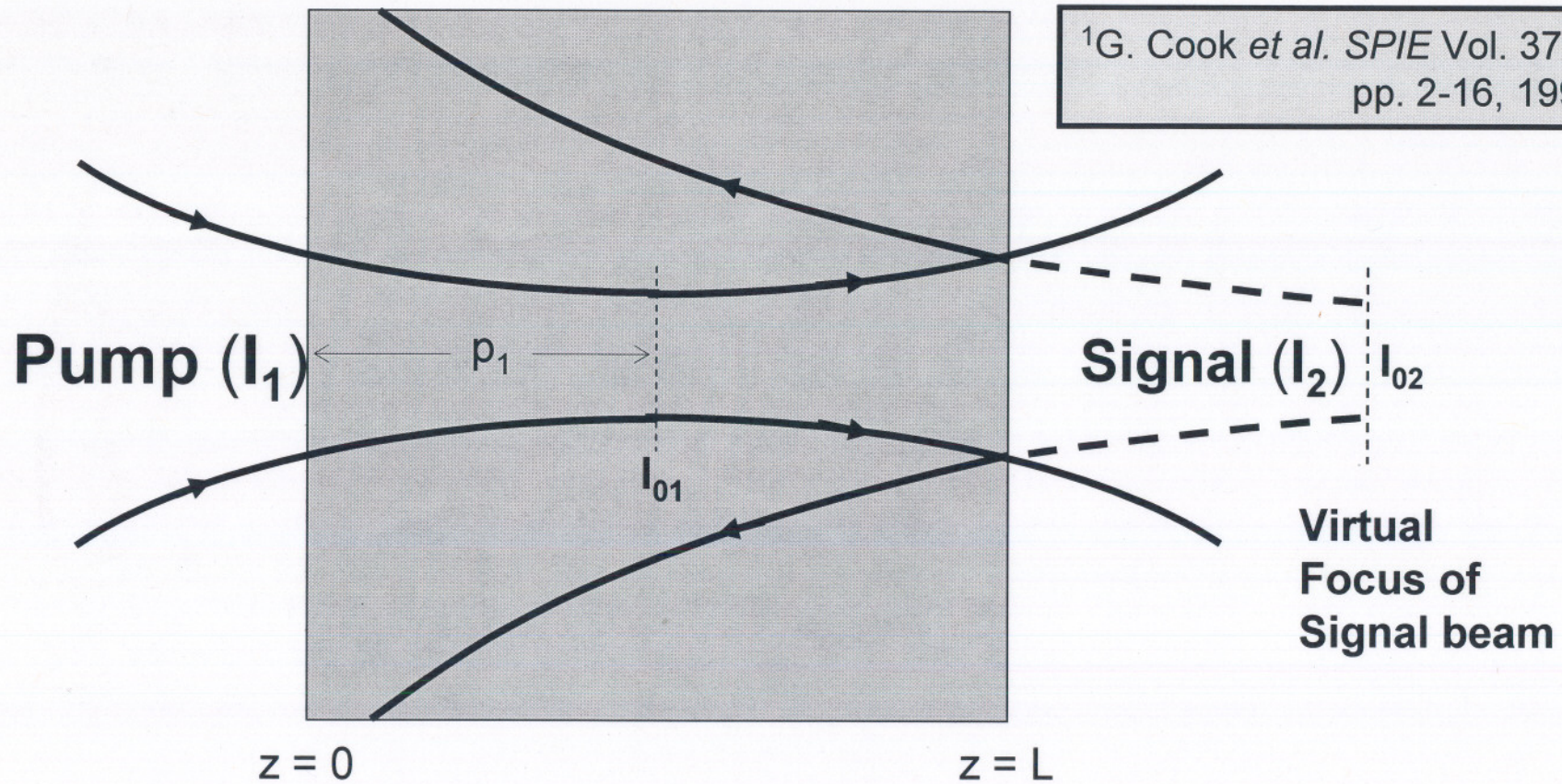


# Decay time vs. rear reflectivity





# Theoretical Model<sup>1</sup>



<sup>1</sup>G. Cook *et al.* SPIE Vol. 3798  
pp. 2-16, 1999

$$I_{01} = \frac{(1 - R_f) P_{inc}}{\pi r_0^2} ; \quad I_1(z) = \frac{I_{01}}{1 + \left[ \frac{(z - p_1)^2}{z_R^2} \right]} ; \quad I_2(z) = \frac{I_{02}}{1 + \left[ \frac{[z - (2L - p_1)]^2}{z_R^2} \right]}$$



# Coupled Equations at Steady State



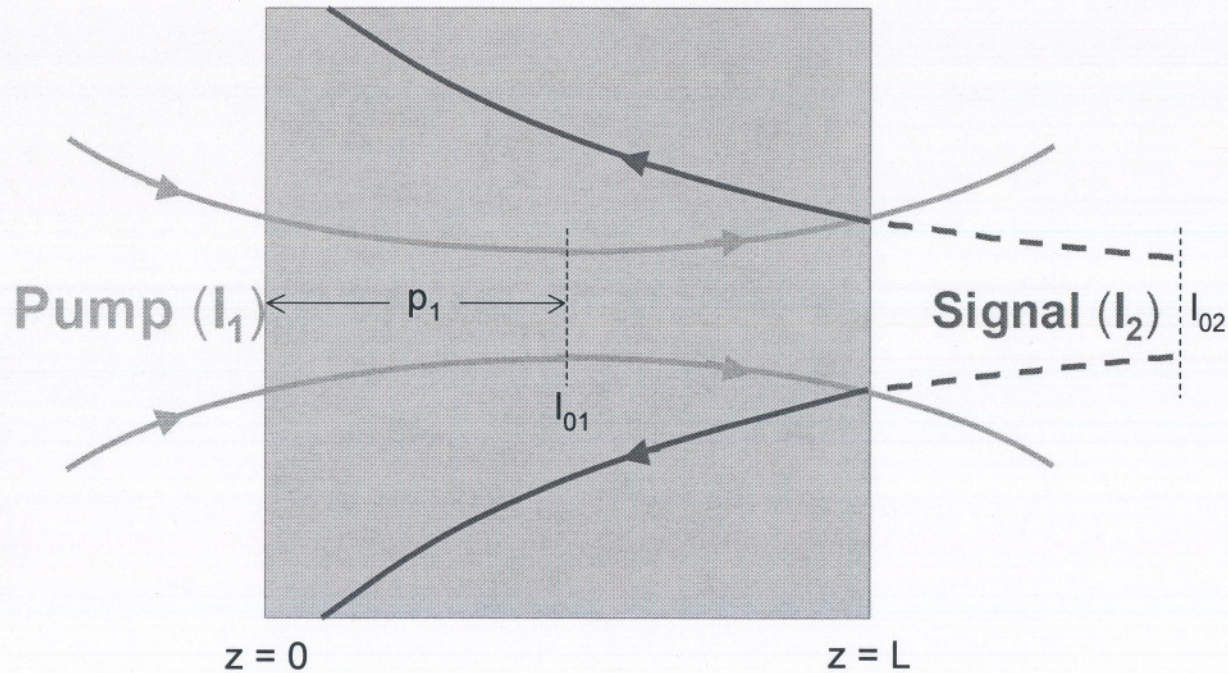
$$\frac{dI_1}{dz} = \frac{-2(z - p_1)I_1}{z_R^2 + (z - p_1)^2} - \alpha I_1 - \frac{\Gamma I_1 I_2}{I_1 + I_2 + I_d}$$
$$\frac{dI_2}{dz} = \frac{-2(z - (2L - p_1))I_2}{z_R^2 + (z - (2L - p_1))^2} + \alpha I_2 - \frac{\Gamma I_1 I_2}{I_1 + I_2 + I_d}$$

- First term accounts for the diffraction of the beams.
- Second term accounts for the linear absorption, where  $\alpha$  is the linear absorption coefficient.
- Last term represents the two beam coupling between the two beams.  $\Gamma$  is the coupling coefficient between the two beams,  $I_d$  is the thermal equivalent intensity<sup>1</sup>, representative of the effect of the dark conductivity in the crystal. (Dark conductivity erases grating)
- These equations are solved numerically using a shoot and solve method.

<sup>1</sup>G. Cook et al. *SPIE* Vol. 3798  
pp. 2-16, 1999



# Calculating Two Beam Coupling



|          |         |          |
|----------|---------|----------|
| $I_1(0)$ | Known   | $I_2(L)$ |
| $I_2(0)$ | Unknown | $I_1(L)$ |

$$\text{TBC} \sim I_1(L)/I_1(0)$$



# Summary

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1. Coating the rear c-surface, we are able to produce a controlled range of rear reflectivity on a photorefractive  $\text{LiNbO}_3$  crystal.
2. The contra-directional two-beam coupling does not vary significantly with reduced rear reflection. This agrees with theoretical calculation
3. The time response of two beam coupling increases with reduced reflectivity.
4. Future work will produce similar work on other types of photorefractive crystals.