LIGO

Enhanced LIGO Modulator

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eLIGO phase modulator

- LIGO is currently being upgraded to eLIGO
- Laser power will be increased to 30 W
- Electro-optic modulators (EOMs) must be replaced.
  - LiNbO3 modulators would suffer from severe thermal lensing or might even break
- eLIGO devices (techniques) will be used in AdvLIGO

Overview eLIGO EOMs

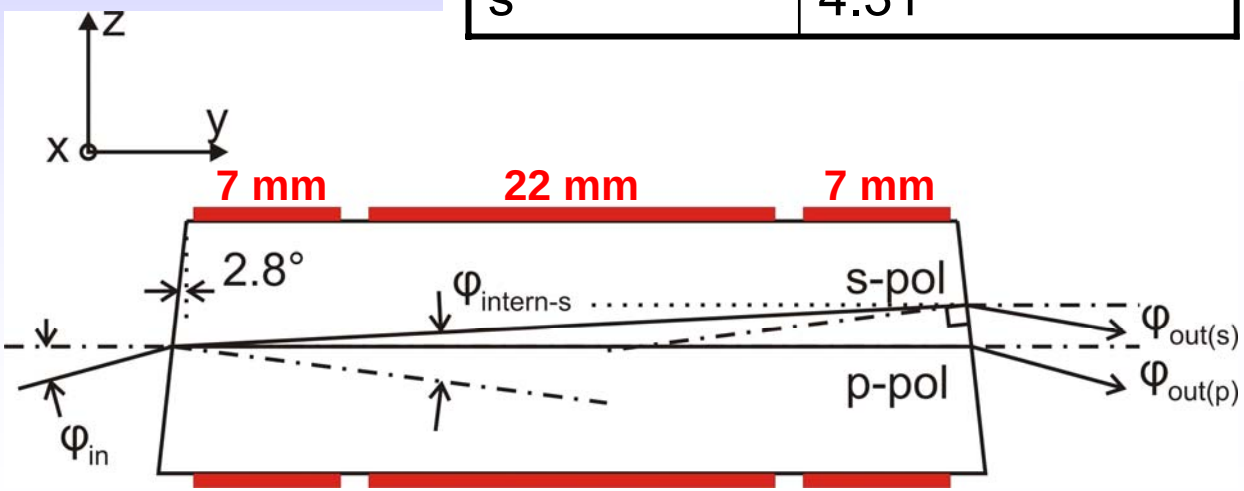
- eLIGO EOMs
  - Lithium niobate (LiNb03), used in initial LIGO, not satisfactory
    - Thermal lensing / Damage / Residual absorption
  - Choose RTP (rubidium titanyl phosphate - RbTiOPO4) as EO material
    - RTP has significantly lower absorption and therefore thermal lensing.
  - Use custom made housing to separate the crystal housing from the housing for the resonant circuit.
    Advantage: Resonant frequencies can be changed without disturbing the optical alignment.
  - Use wedged crystals to reduce spurious amplitude modulation
    Additional advantage: EOM acts as polarizer

Wedged RTP crystal

- Wedged crystal separates the polarizations and acts as a polarizer.
  - This avoids cavity effects and reduces amplitude modulation.

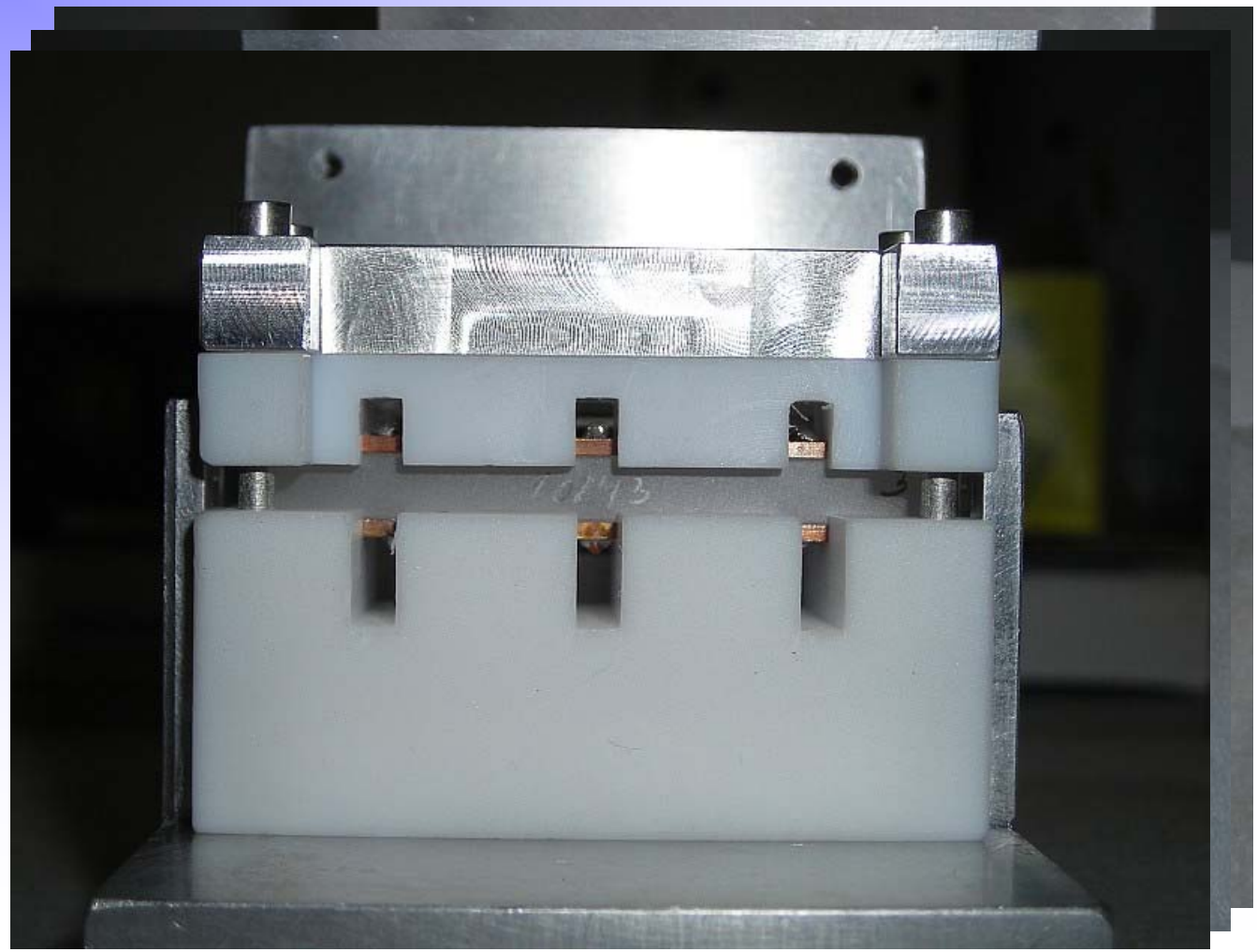
Polarization	Angle [degrees]
p	4.81
s	4.31

- AR coatings (< 0.1%) on crystal faces.



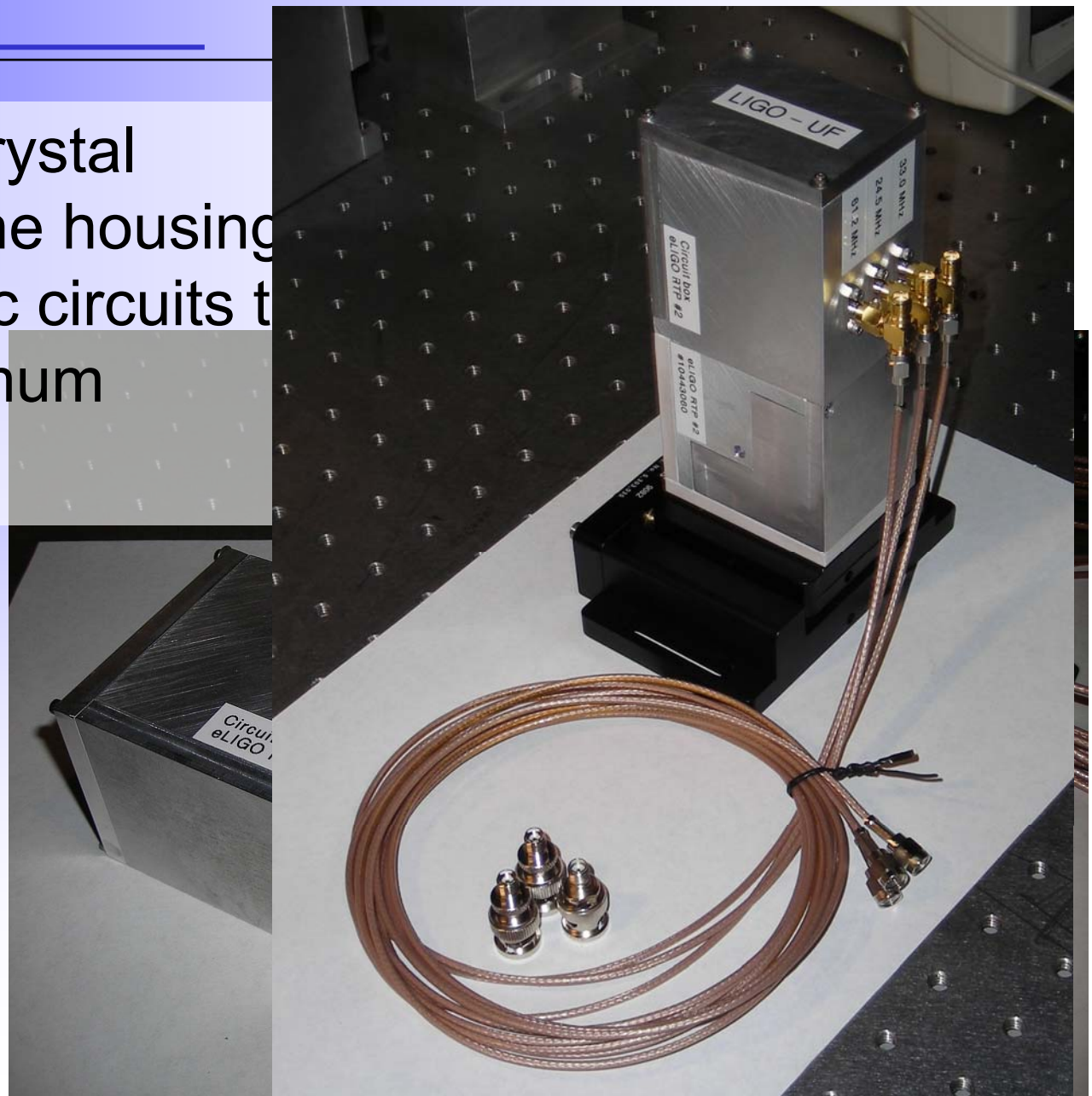
Three Modulations / Single Crystal design

- Use one crystal but three separate pairs of electrodes to apply three different modulation frequencies at once.
- Electrodes:
  - 7 mm
  - 22 mm
  - 7 mm



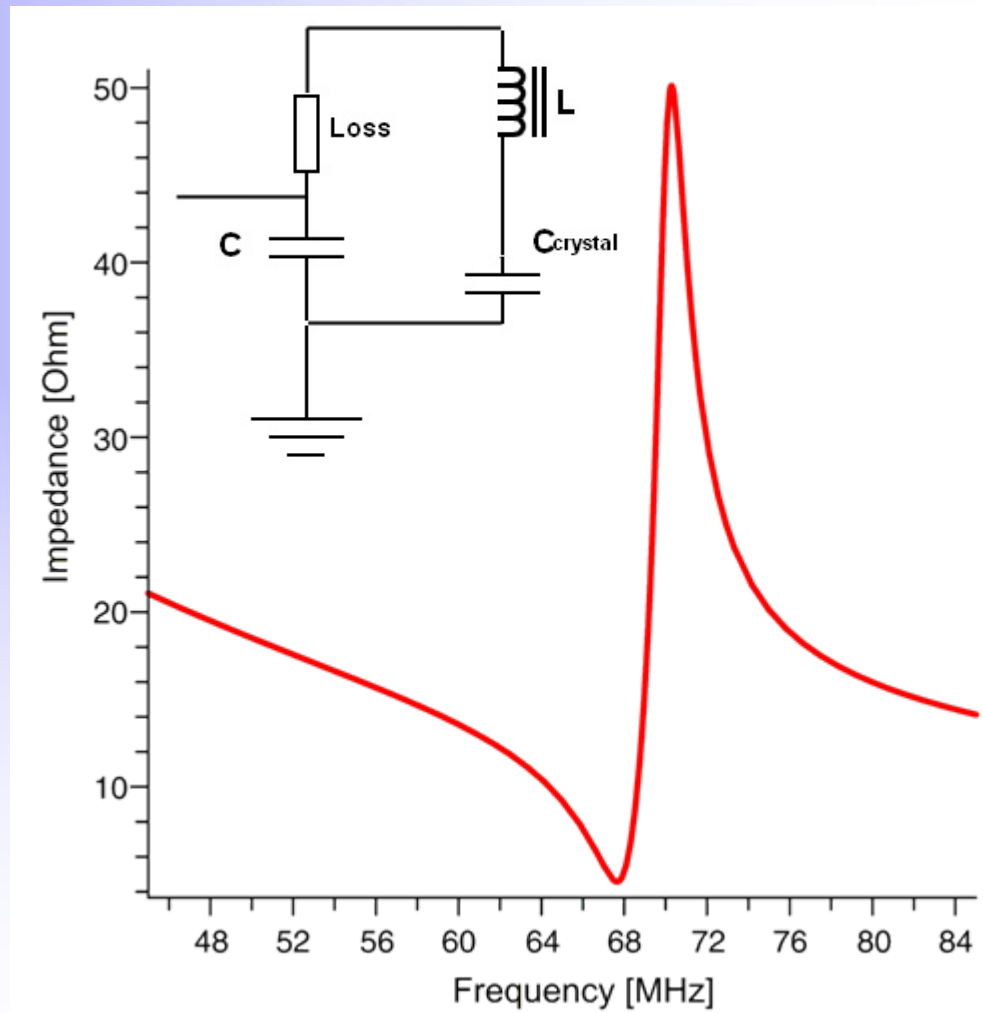
Industry-quality housing

- Separate the crystal housing from the housing of the electronic circuits t maintain maximum flexibility.



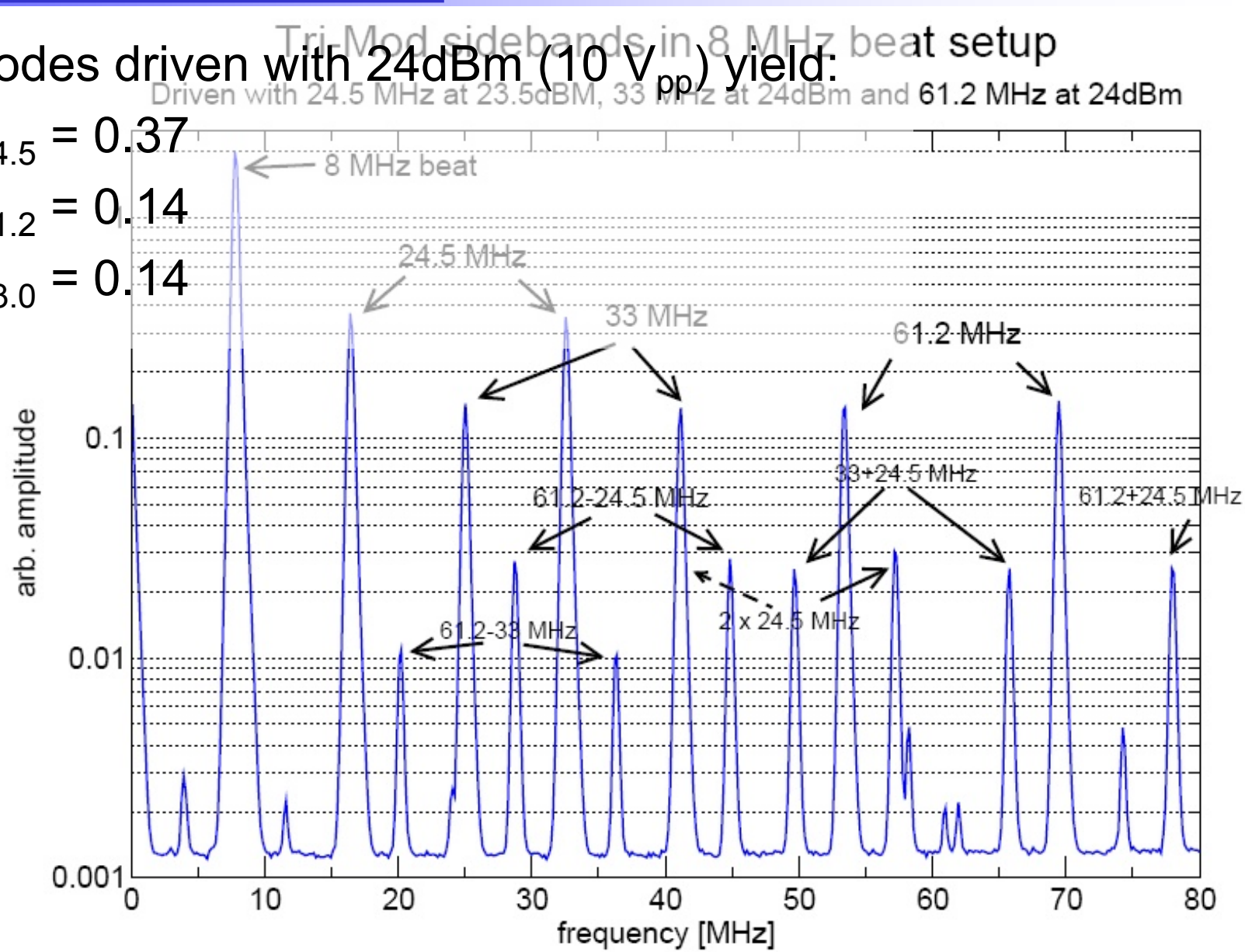
Resonant circuit

- Impedance matching circuit in separate housing.
- Resonant circuit with 50 Ω input impedance.
- Current version at CalTech has three resonant circuits:
  - 24.5 / 33.0 / 61.2 MHz



Modulation index measurement

- Electrodes driven with 24dBm (10 V_{pp}) yield:
  - $m_{24.5} = 0.37$
  - $m_{61.2} = 0.14$
  - $m_{33.0} = 0.14$



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Thermal properties

- Use a YLF laser was used to measure the thermal lensing.
  - Full Power = 42 W
  - Beam Waist = 0.5 mm (at RTP)
  - 4x4x40 mm RTP crystal

Axis	Focal length
X-axis	3.8 m
Y-axis	4.8 m

- compare with LiNbO3 (20 mm long):
  $f_{thermal}$ ~ 3.3 m @ 10 W

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RFAM

- Wedged geometry suppresses amplitude modulation. (No polarisation rotation possible)
  - Cursory result for the current version:
    $\Delta I/I < 10^{-5}$ at Ω_{mod} = 25.4 MHz / m = 0.17
- Final characterization underway
  - Including RFAM at high power (30W) levels.

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What is left to do?

- Continue testing at CalTech with 30W eLIGO laser
  - RFAM
  - Thermal lensing
  - Long-term stability
  - EMI
- Start 200W (AdvLIGO) testing ...
  - Next week ...

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Supplementary material

RTP Thermal properties

Properties	Units	RTP	RTA	KTP	$LiNbO_3$
dn_x/dT	10^{-6}/K	-	-	11	5.4
dn_y/dT	10^{-6}/K	2.79	5.66	13	5.4
dn_z/dT	10^{-6}/K	9.24	11.0	16	37.9
κ_x	W/Km	3		2	5.6
κ_y	W/Km	3		3	5.6
κ_z	W/Km	3		3	5.6
α	cm^{-1}	< 0.0005	< 0.005	< 0.005	< 0.05
Q_x	1/W	-	-	2.2	4.8
Q_y	1/W	0.047	0.94	2.2	4.8
Q_z	1/W	0.15	1.83	2.7	34

Optical and electrical properties

Properties	Units/conditions	RTP	RTA	$LiNbO_3$
Damage Threshold	MW/cm^2,	>600	400	280
n_x	1064nm	1.742	1.811	2.23
n_y	1064nm	1.751	1.815	2.23
n_z	1064nm	1.820	1.890	2.16
Absorption coeff. α	cm^{-1} (1064 nm)	< 0.0005	< 0.005	< 0.005
r_{33}	pm/V	39.6	40.5	30.8
r_{23}	pm/V	17.1	17.5	8.6
r_{13}	pm/V	12.5	13.5	8.6
r_{42}	pm/V	?	?	28
r_{51}	pm/V	?	?	28
r_{22}	pm/V			3.4
$n_z^3 r_{33}$	pm/V	239	273	306
Dielectric const., ε_z	500 kHz, 22 °C	30	19	
Conductivity, σ_z	$\Omega^{-1}cm^{-1}$, 10 MHz	$\sim 10^{-9}$	3×10^{-7}	
Loss Tangent, d_z	500 kHz, 22 °C	1.18	-	