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Active components for 2µm fibre lasers

Jon Ward- 2015

Key Components

- AO Modulator
  - TeO_2
  - Chalcogenide Glass
  - Si Pulse Picker

- AO Tunable Filter
  - Narrow-resolution Quasi-Collinear 2µm AOTF
  - Null frequency-shift 2µm AOTF-pair

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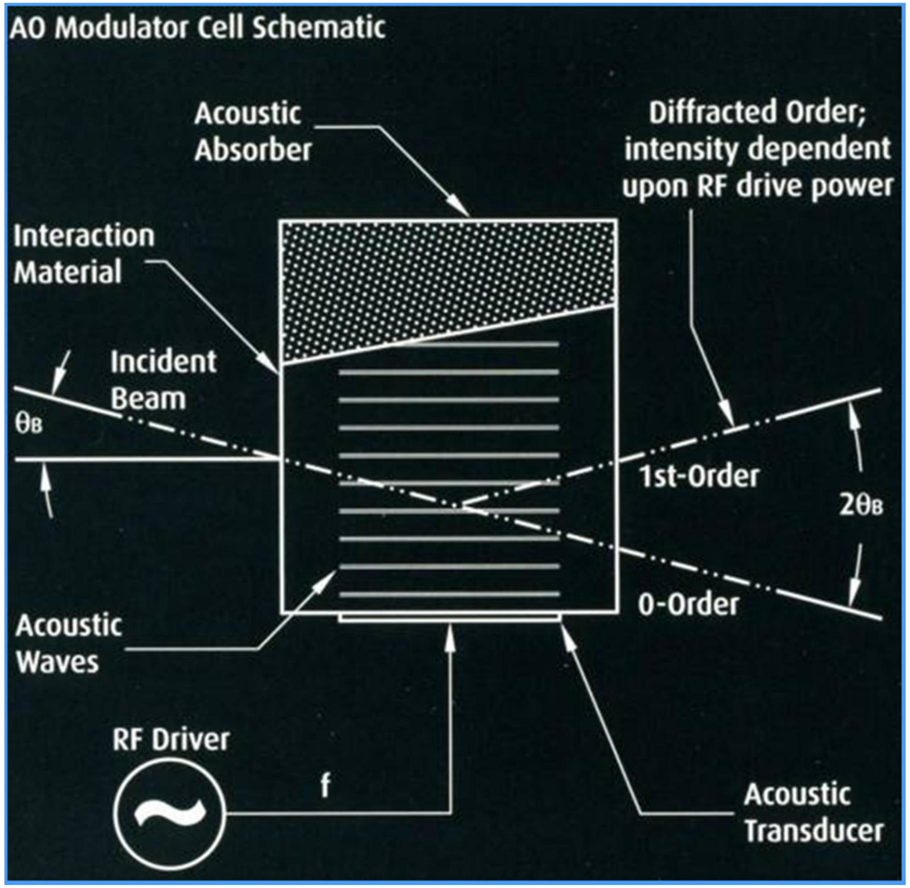
Acousto-Optics

The Principle



- Acoustic beam creates a sinusoidal refractive-index variation (photo-elastic effect)
- Periodic variation acts as diffraction-grating
- Light diffracted when matching-condition is satisfied
  - Matching is a function of optical and acoustic wavelengths
- Depth of diffraction is a function of the index contrast
  - Can be set by the acoustic intensity
- Diffracted beam can be intensity modulated
- Diffracted beam is Frequency-Shifted (Doppler Effect)

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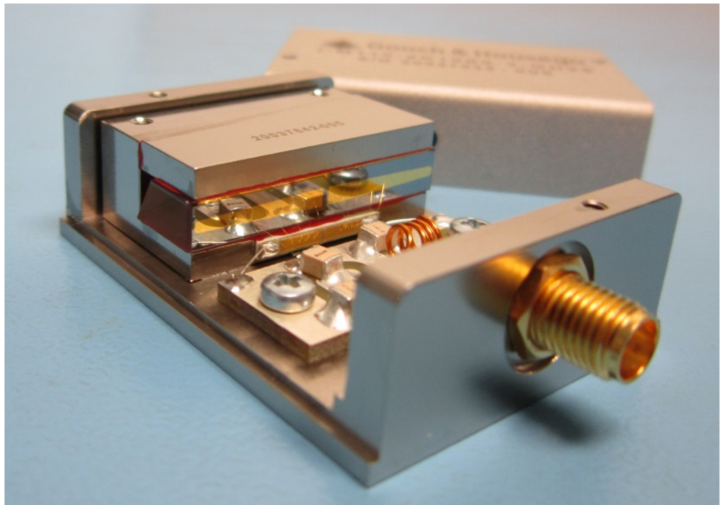
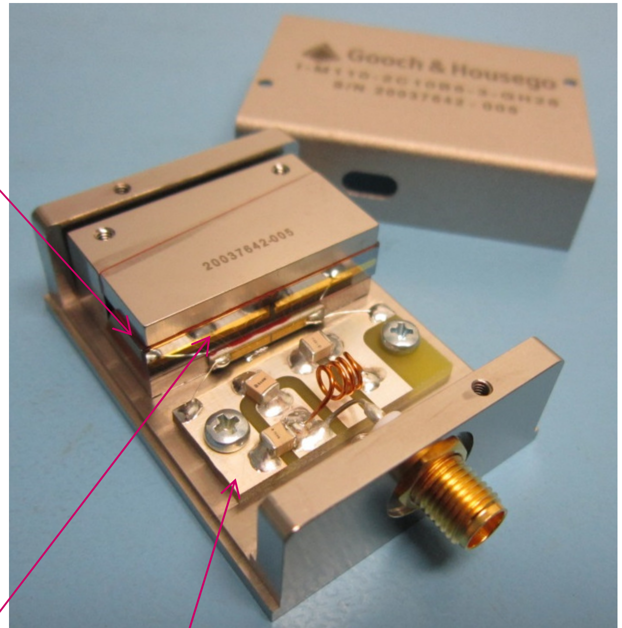
Acousto-Optics

- Features
  - Solid-State: no moving parts
  - Fast switching-time
    - <10ns for fast AOM
    - <10μs for Frequency-Shifter, Tunable Filter etc



AO Cell



Acoustic transducer

Impedance Matching network

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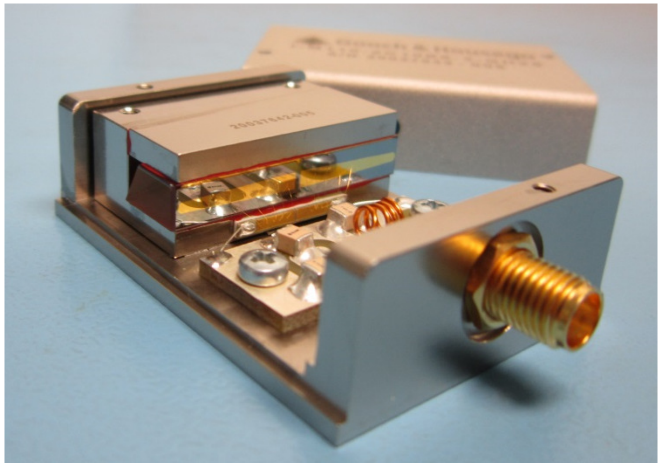
Acousto-Optics



- Intra-cavity modulators
  - AO Q-switches
  - AO Mode-lockers
  - AO Cavity Dumpers

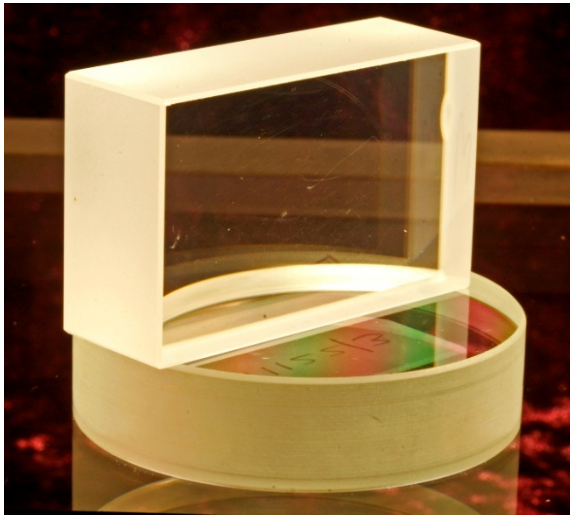
- Extra-cavity modulators
  - AO Modulators
  - AO Pulse Pickers
  - AO Beam Deflectors
  - AO Frequency-Shifters
  - AO Tunable Filters

- RF Drivers

Choice of AO Material

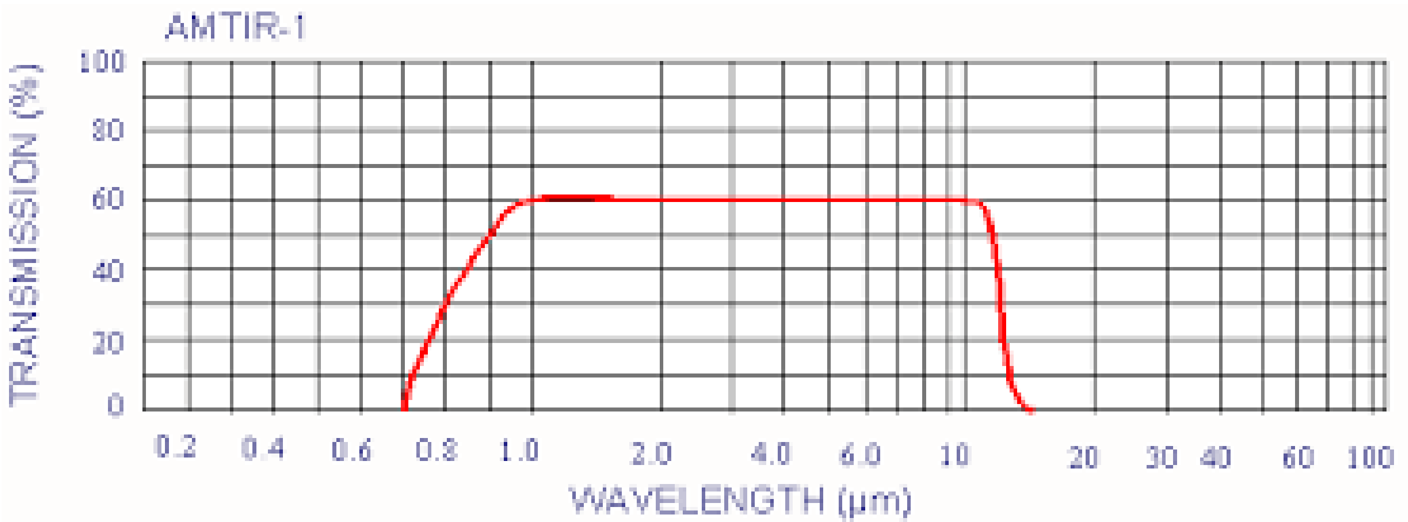
- The optical medium should be transparent at the required wavelength(s)

- The material should have good Acousto-Optic properties
  - Efficient AO interaction
  - Reasonable acoustic attenuation
  - Compatible with manufacturing process



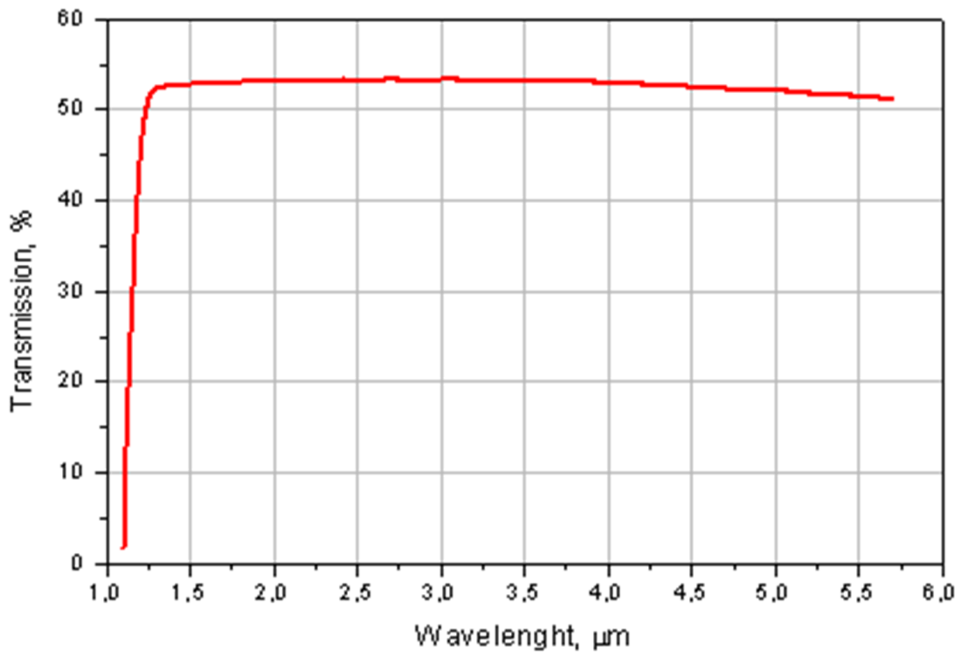
Chalcogenide Glass

- AMTIR-1 $Ge_{33}As_{12}Se_{55}$
  - Large M_2 ($>200 \times 10^{-15} s^3/kg$)
  - Transparent at 2µm
  - Significant acoustic attenuation
  - Poor thermal-conductivity
  - Challenging to process – but problems have been solved



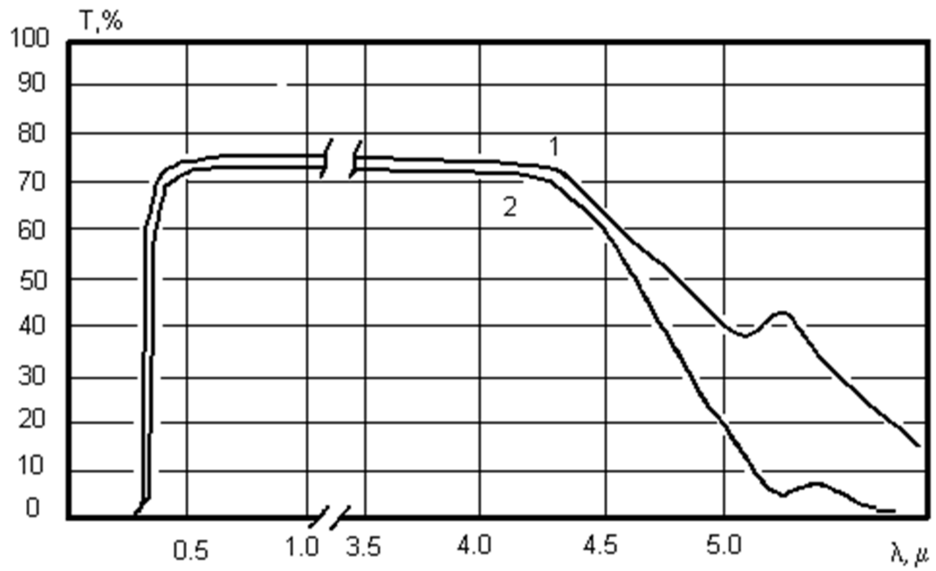
Silicon

- Single Crystal Silicon (Si)
  - Transparent at 2μm
    - High index n=3·46
  - Reasonable M_2
    - ~$11x10^{-15}s^3$/kg isotropic
    - Polarisation sensitive
  - Fast acoustic velocity (v=$9310ms^{-1}$)
  - Straightforward to process
  - Good thermal properties



Tellurium Dioxide

- Single Crystal Tellurium Dioxide (TeO_2)
  - Supports both “isotropic” & “anisotropic” AO interactions
  - Transparent at 2μm
  - Reasonable M_2
    - $\sim 20 \times 10^{-15} s^3/kg$ isotropic
    - $\sim 600 \times 10^{-15} s^3/kg$ anisotropic
  - Well understood
    - Used extensively for VIS & SWIR



TeO2 transmission, 20 mm thick sample
1 - O-polarization, 2 - E-polarization

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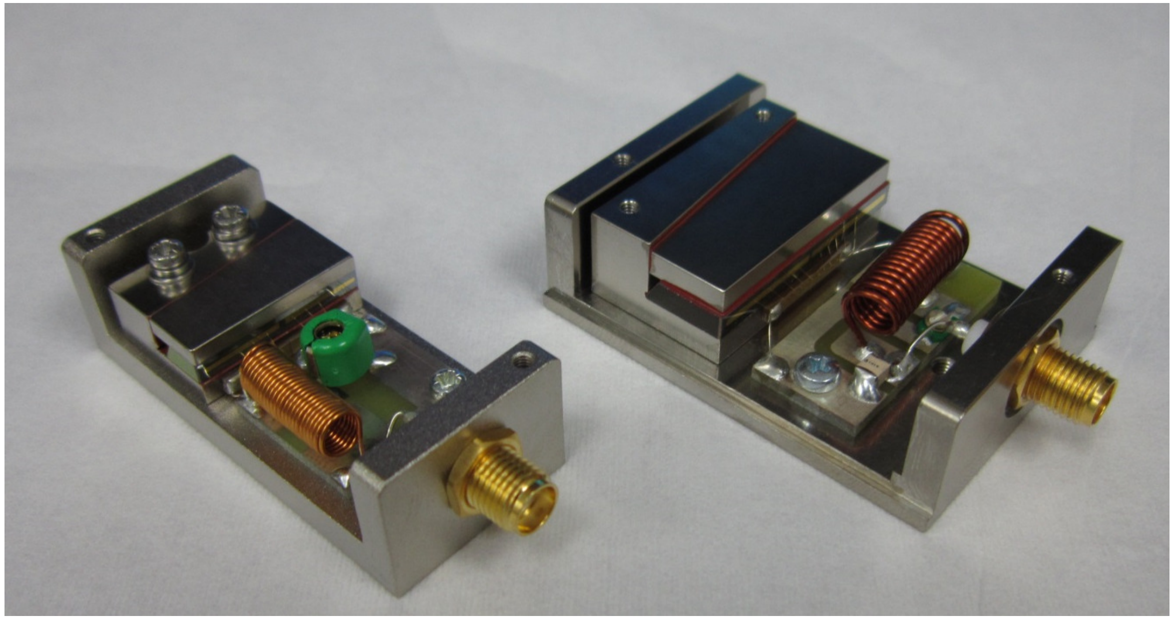
AO Modulators @ 2µm



The TeO_2 based AOM (Right) showing the longer cell than the AMTIR-1 chalcogenide glass based AOM (Left).

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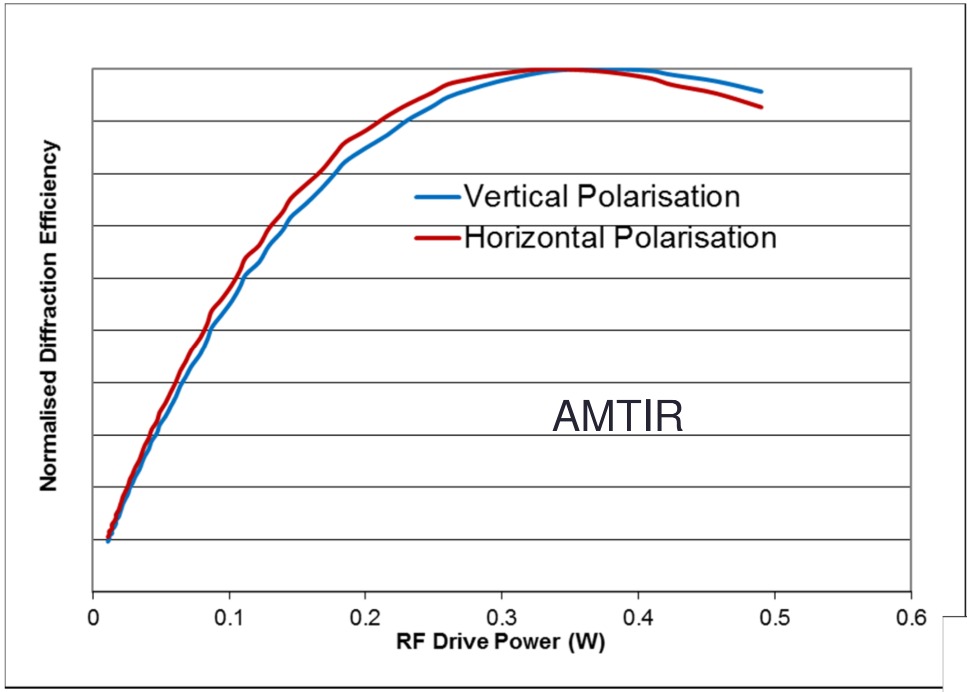
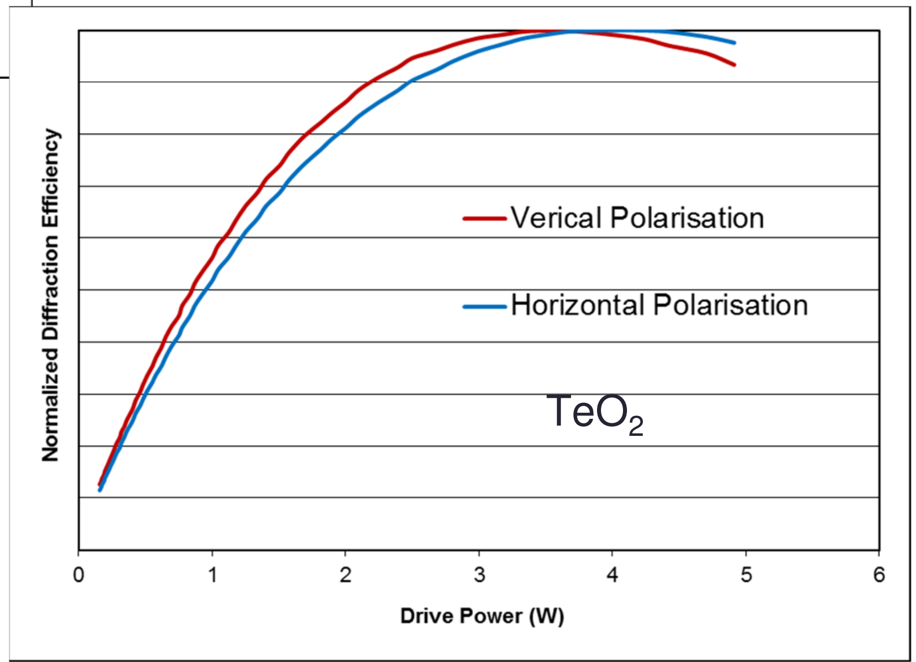


Diffraction Efficiency vs drive power for the AMTIR-1 chalcogenide glass based AOM showing reduced dive power & polarisation dependence



Diffraction Efficiency vs drive power for the TeO_2 based AOM showing polarisation dependence

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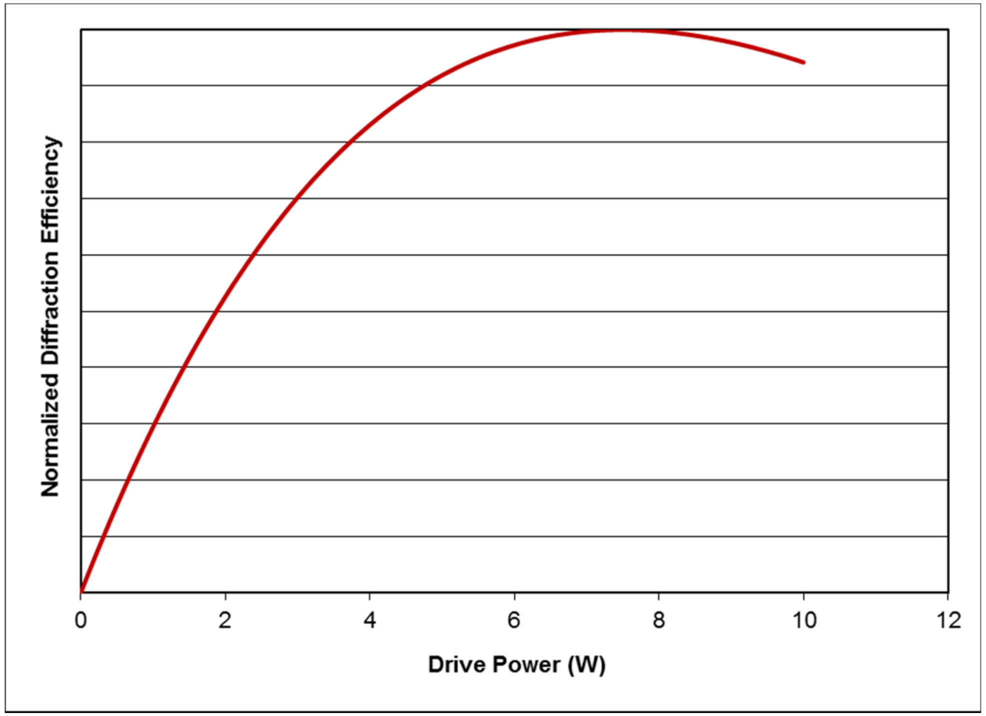
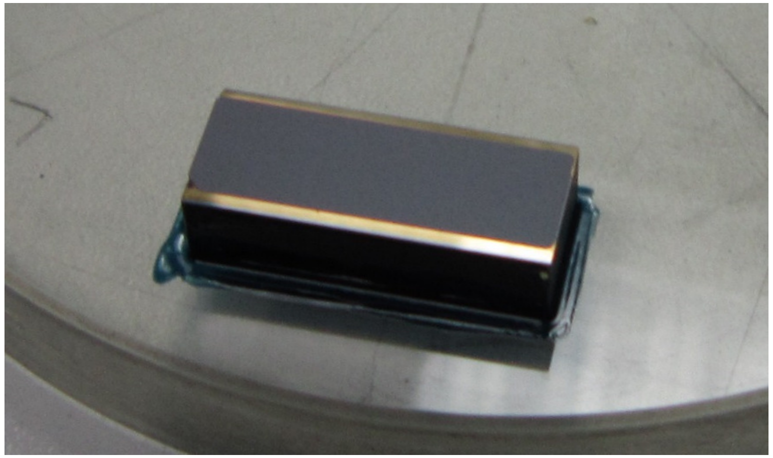
Si Pulse-Picker (fast risetime)

Device:	AO Modulator
Interaction Material:	Silicon
Wavelength:	2100nm
AR Coating Reflectivity:	≤ 0·2% /surface
RF Frequency:	250MHz
Active Aperture:	0·25mm (Height)
Input Polarisation:	Linear – horizontal wrt base
Risetime:	**15ns** (For 0·2mm spot)
Beam Diameter:	200μm
Diffraction Efficiency:	> 85%
Typical RF Drive Power:	7.5W
Input Impedance:	50Ω





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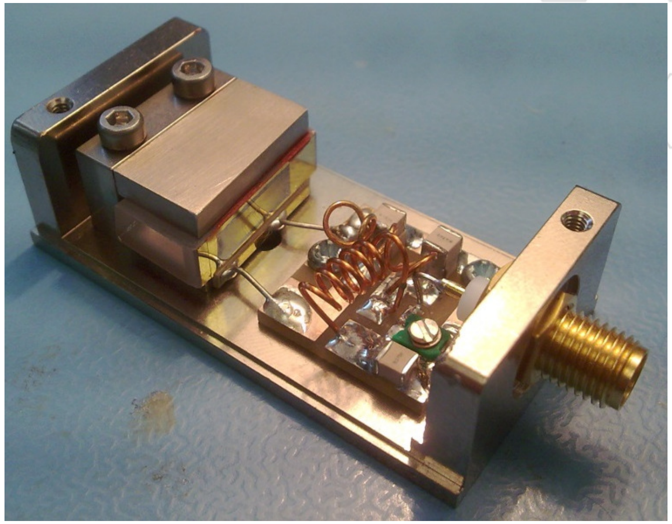
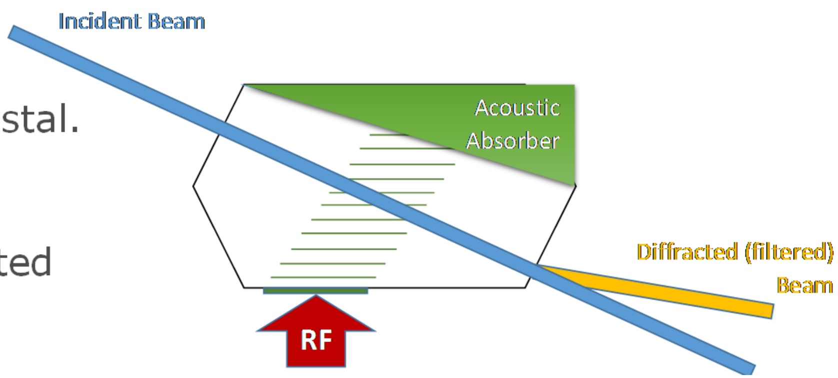
What is an AOTF?

- An AOTF (Acousto Optic Tunable Filter) is an optical passband filter that is tunable
- AOTFs are made from crystals whose optical properties can be controlled by sending sound waves through them.
- Ultrasound in the crystal generates a refractive index grating (photo-elastic effect) that diffracts light that satisfies certain matching conditions.
- The sound waves are generated by applying a sinusoidal radio-frequency electrical signal to a specially designed transducer bonded to the crystal.
- As a result, the key filter parameters - centre wavelength & throughput (ie intensity of diffracted light) - are under complete electronic control.
- There are no moving parts, no maintenance, and an indefinite lifetime.





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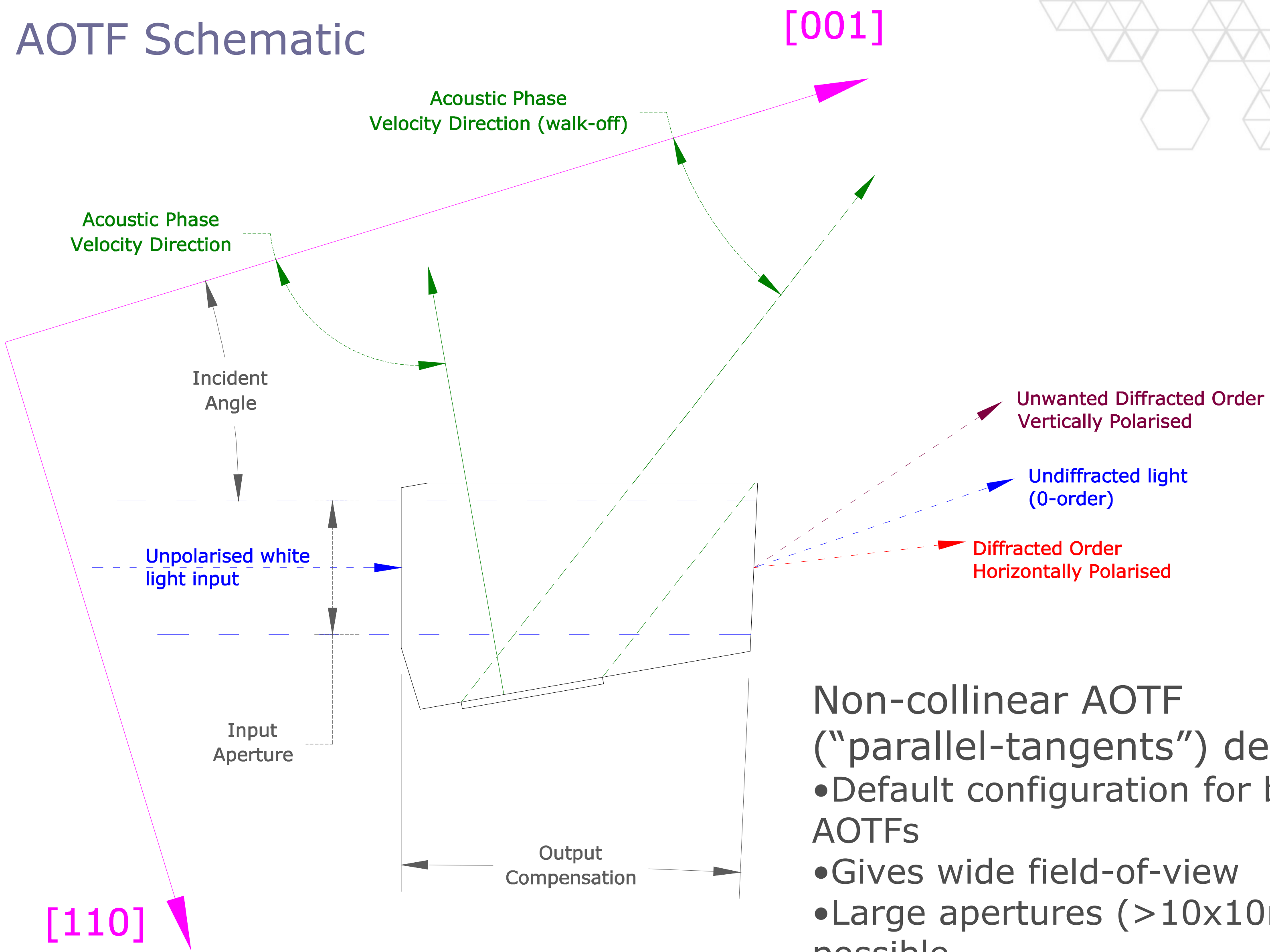
AOTF Schematic



Non-collinear AOTF ("parallel-tangents") design

- Default configuration for bulk-optic AOTFs
- Gives wide field-of-view
- Large apertures (>10x10mm) are possible

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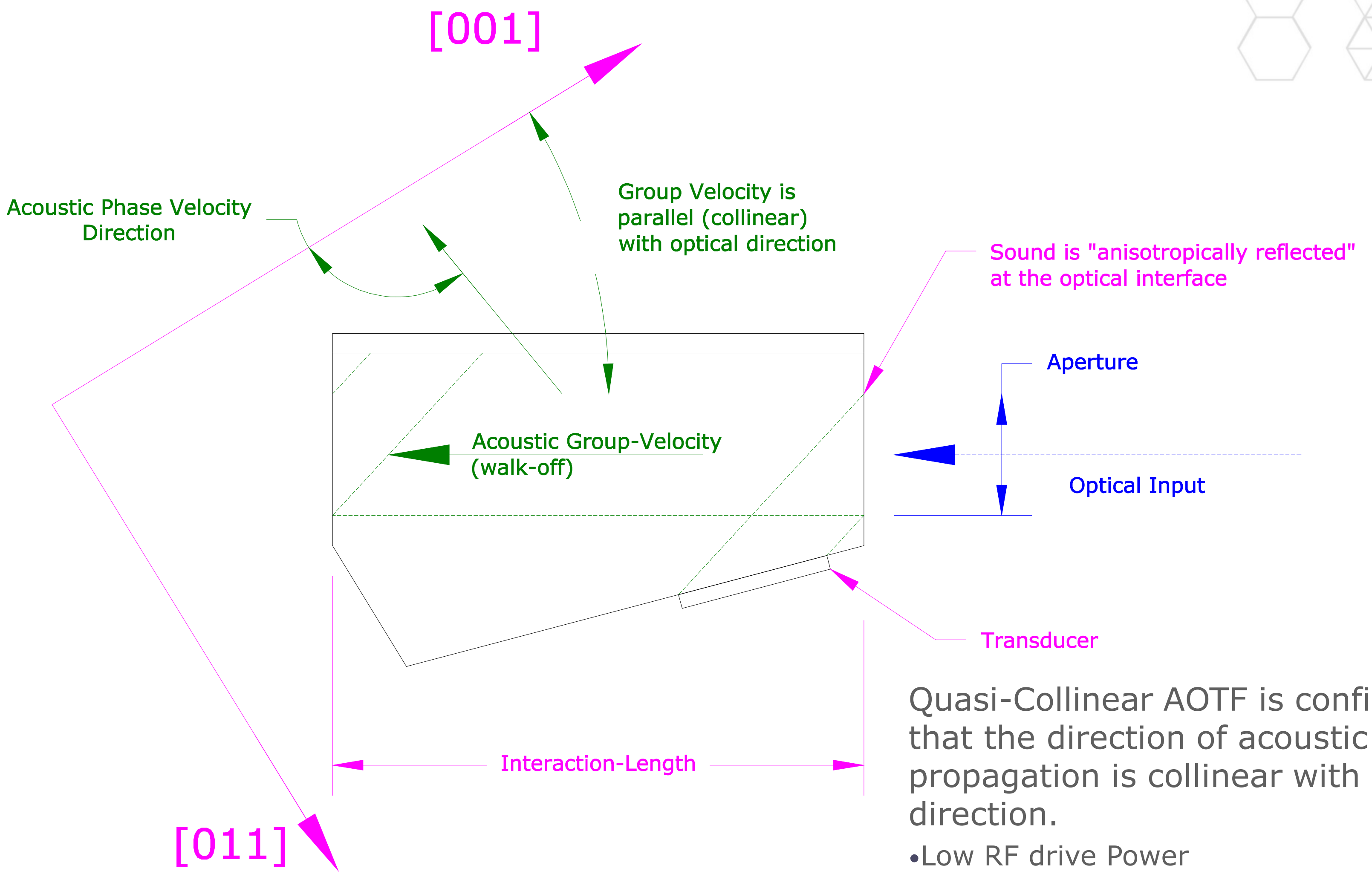
Quasi-Collinear AOTF concept



Quasi-Collinear AOTF is configured so that the direction of acoustic energy propagation is collinear with the optical direction.

- Low RF drive Power
- Narrow resolution with inherent side-lobe suppression
- Narrow field-of-view

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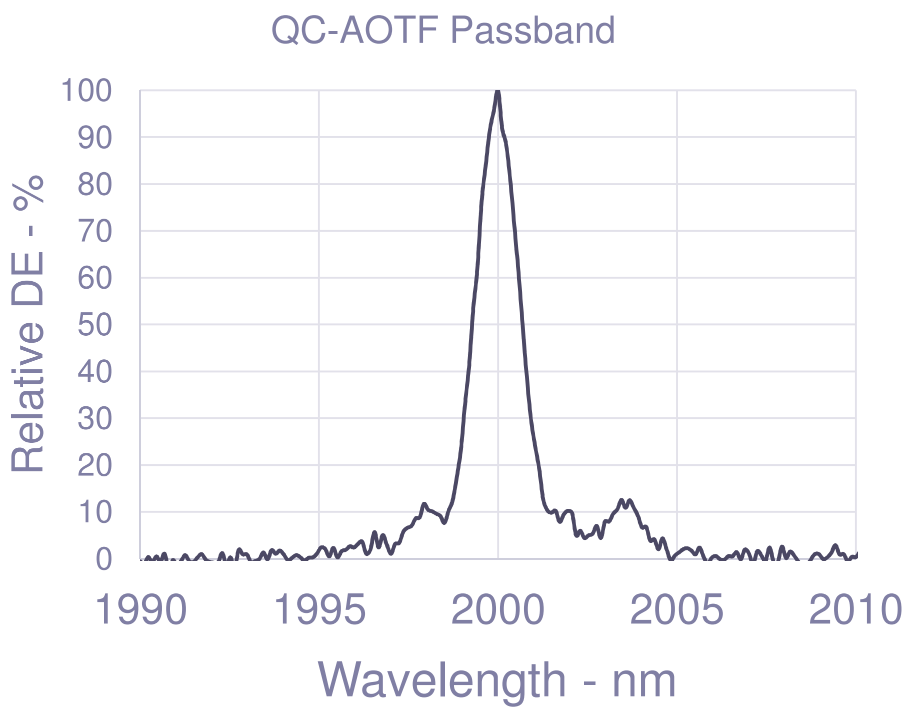
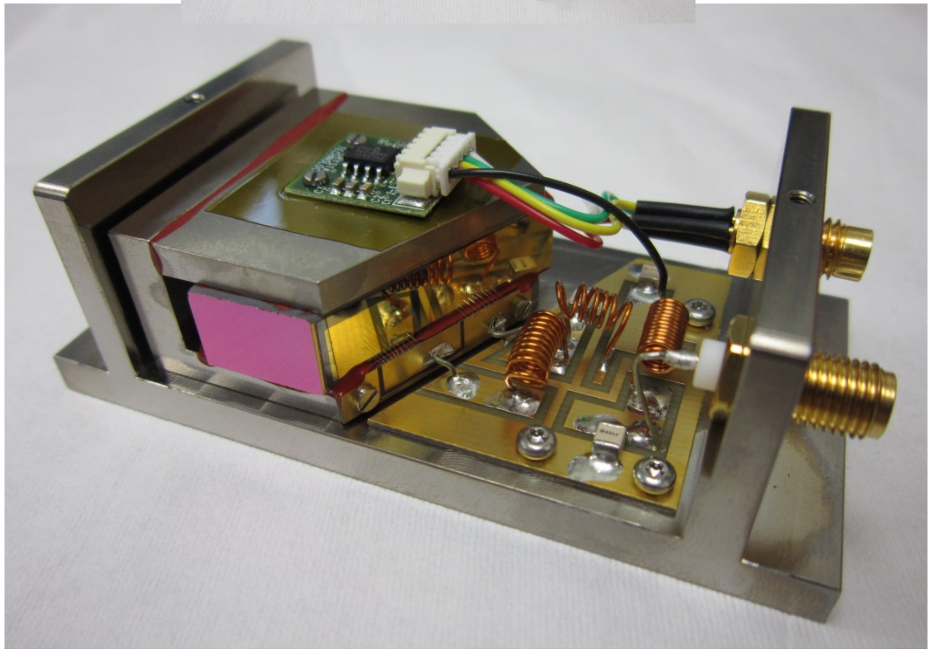
Quasi-Collinear AOTF

- Quasi-Collinear AOTF
  - Narrow resolution
    - <1·5nm @ 2μm
  - Low Drive Power
    - 400mW





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AOTF in Reverse-Pass (K-Space Representation)

K-Space Representation

- k_i is incident light momentum vector
- k_d is diffracted light momentum vector
- K_a is acoustic (phonon) momentum vector

Strong diffraction occurs when momentum vector triangle is closed (conservation of momentum)

$$k_i \pm K_a = k_d$$

o-ray is diffracted to e-ray (or vice-versa)

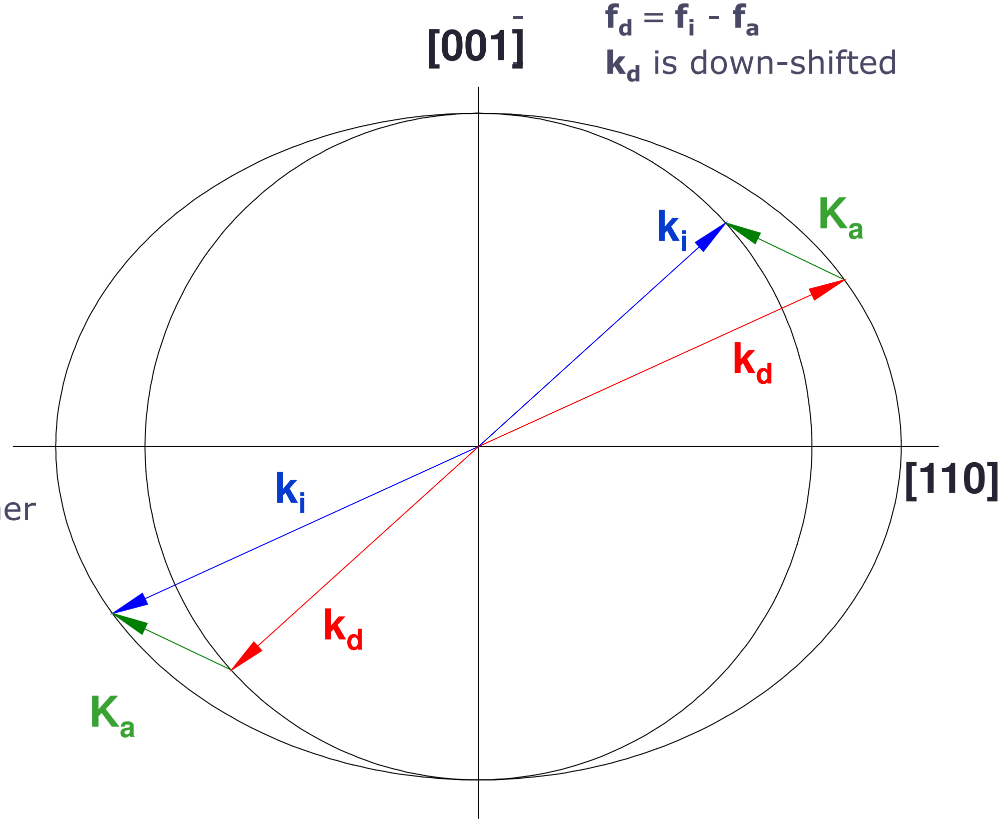
Conservation of energy leads to the relation

$$f_d = f_i \pm f_a$$

ie the optical frequency is Doppler-shifted either up or down depending on the direction of K_a.

Forward-Pass; 1st quadrant

- k_i is o-ray
- k_d diffracted to e-ray
- $f_d = f_i - f_a$
- k_d is down-shifted



Reverse-Pass; 3rd quadrant

- k_i is e-ray
- k_d diffracted to o-ray
- $f_d = f_i - f_a$
- k_d is down-shifted

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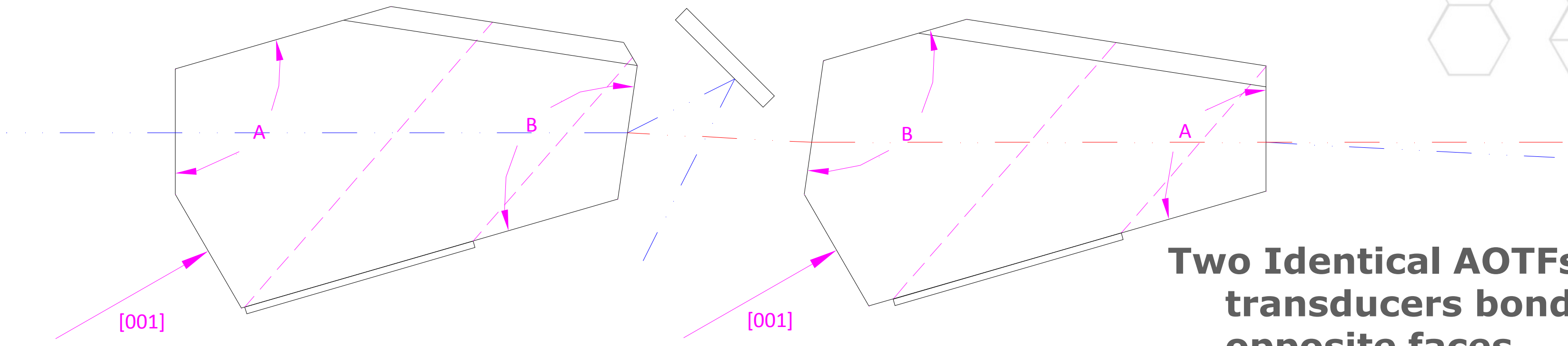
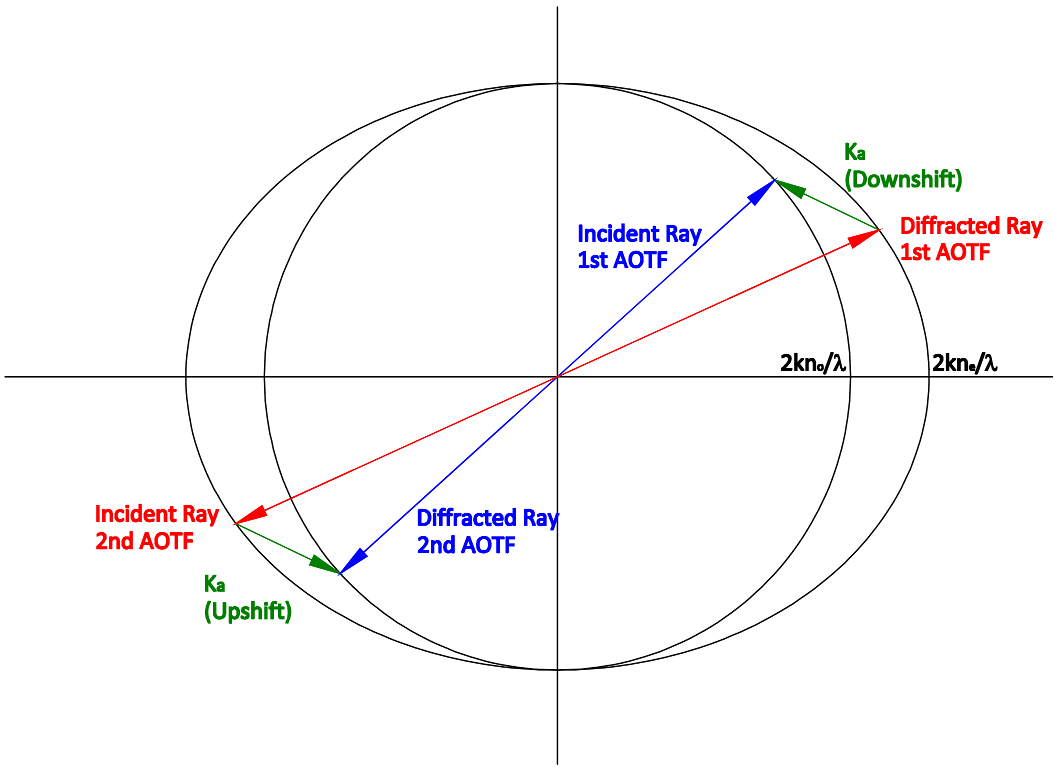
Null-Shift AOTF Pair (K-Space Representation)





Two Identical AOTFs with transducers bonded to opposite faces

- 1st AOTF
  - o-ray incident, is **down-shifted** (represented in 1st quadrant of k-space diagram). Transducer bonded in the "usual" manner.
- 2nd AOTF
  - Cell identical to 1st AOTF; e-ray incident, is **up-shifted**. Transducer bonded to "opposite" face
- AOTFs aligned so that [001] directions are parallel
  - output face (AOTF-1) and input face (AOTF-2) will be parallel

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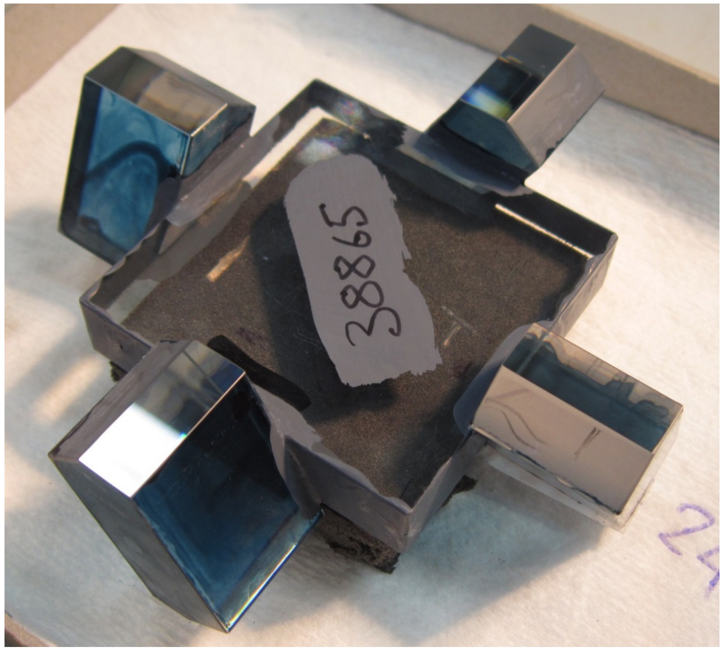
Null-Shift AOTF Pair



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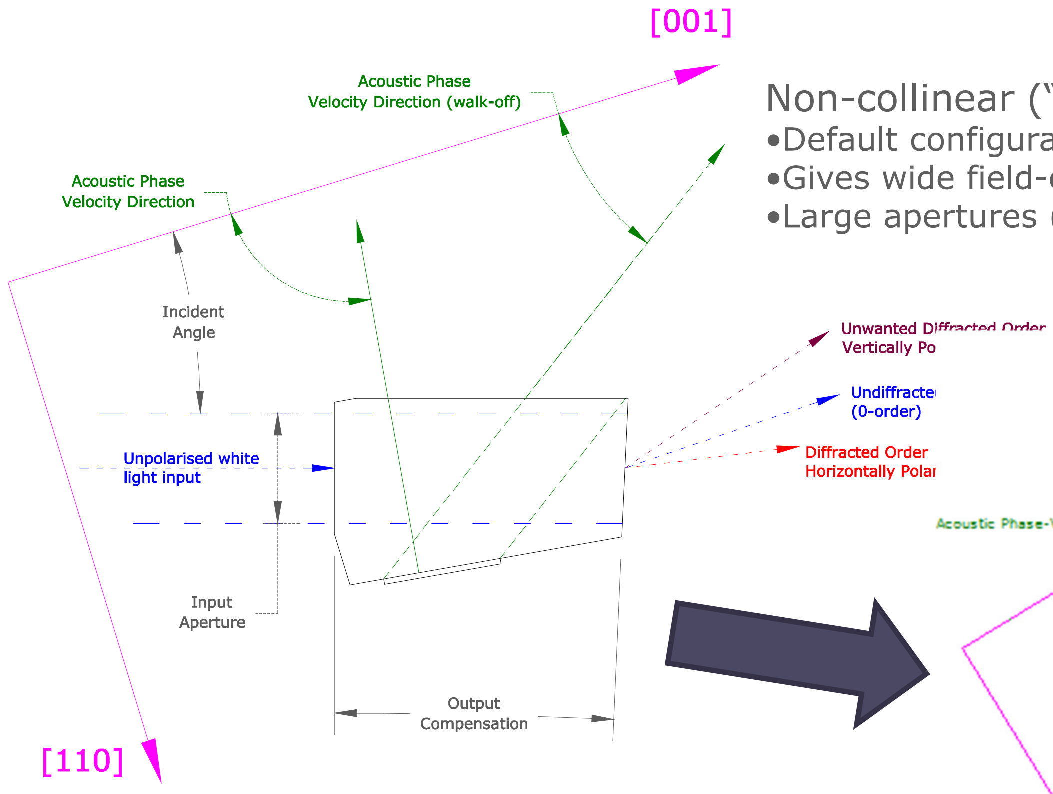

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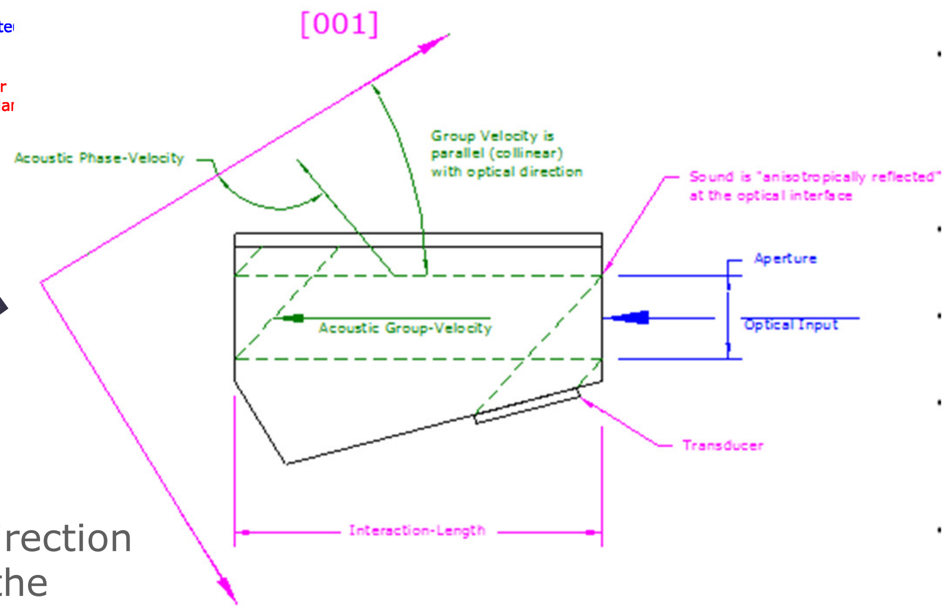

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Quasi-collinear design

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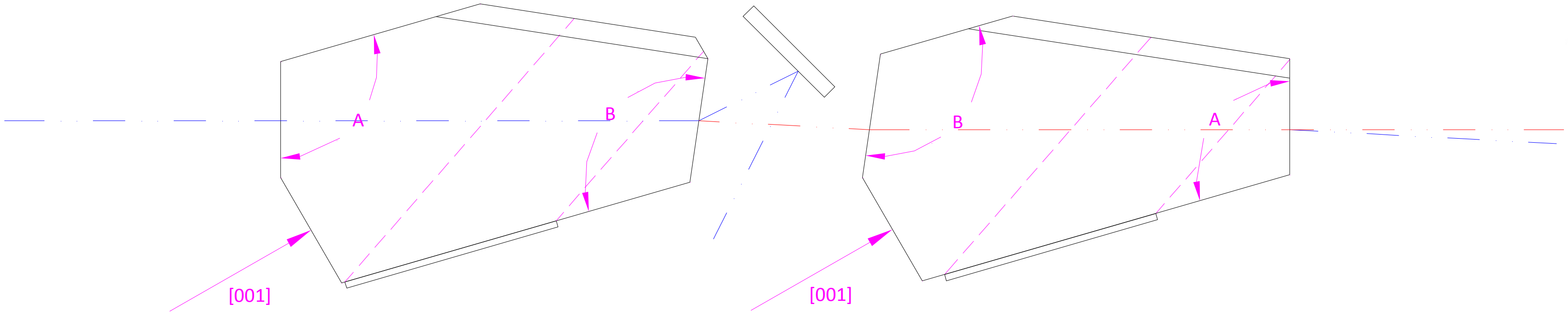
IL0 Null frequency-shift 2µm AOTF



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