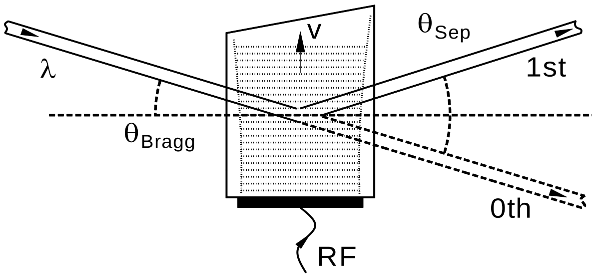
Application Note

AN1101 *Oct 16*

High power Modulation & Deflection of CO_2 Lasers

Basic Principles

It is worth summarising some basic AO theory in order to appreciate the practical application and limitations of AO devices. The diagram below shows the key characteristics of an acousto-optic modulator or deflector.



An AO device works through the interaction of sound (RF) and light. This is achieved via a piezo-electric transducer bonded to one face of a suitable crystalline material. When an RF drive signal is applied to the transducer, a travelling acoustic wave is produced in the crystal. This creates areas of compression and rarefraction, similar to the slits in a diffraction grating.

For practical applications such as modulators and deflectors, AO devices need to operate in the Bragg regime where the majority of the diffracted light appears in one order. This is achieved by having a long interaction length L (equivalent to the optical path length in crystal), and inputting the incident light at a specific angle (Bragg angle).

The frequency of the RF drive determines the first order output angle. The amplitude of the RF drive determines the diffraction efficiency into that first order. In practice IR, scan angles are in the order of 2-3 degrees in the IR and the maximum efficiencies approach 85-90%. This means that there is always at least 10% of the input laser beam in the zero order beam dump.

Considerations for High Power CO_2 Lasers.

- The only practical acousto-optic material in the 2.5 – 12 um range is Germanium (GE). To be effective, the input polarization must be linear and parallel to the diffraction axis.
- Germanium absorbs optical power in the IR - approximately 1.8 – 2.5% / cm at 10.6um. At higher powers, heat induced absorption results in localised variations in refractive index. This creates thermal lensing that will degrade the beam quality. Ultimately if the input power is further increased a point will be reached were thermal runaway occurs and the GE will be damaged.
- We take care to specify the best low loss optical grade GE. Even so, for applications above 100-200W average power, thermal lensing should be considered in the system design.

- Reports from a number of our customers indicate that thermal lensing is controllable if the average optical power density is below a figure of ~10W / mm^2. This is well below the damage threshold - in excess of 50W/mm^2

- For high power lasers it is often necessary to use large aperture AO devices and shape the input beam over the full aperture – typically an elliptical beam through the rectangular active aperture.

- The active aperture height is defined by the transducer height. Since the required RF drive power is increases with aperture height, the maximum transducer height is limited by the maximum RF power that can be safely input to the AO device. For GE devices aperture heights range from 6 – 10mm, requiring RF powers up to 200-250W. As a result all GE devices are water-cooled. (see below). For high modulation duty cycles, most of the heat is generated from the RF drive but the contribution from optical absorption can be significant when the average optical power exceeds 150W.

- The width of the aperture (i.e. along the diffraction axis) is limited by the maximum crystal length. Typically crystals are 30-60mm with specials up to 100mm long. Usually the crystal length is made long enough to accommodate the beam width + 20mm. The final beam width is a compromise between expanding the width to reduce optical power density and keeping the beam width low enough to achieve fast switching times.

- The optical rise time or switching time is defined by the beam width. To a first approximation, the rise time T_r is :

$$Tr \cong 0.65 \times \frac{\text{Beam width}}{\text{Acoustic velocity (V)}}$$

The beam width also defines the resolution for AO deflector applications. The resolution N is given by:

$$N = \frac{\text{Full AO scan angle}}{\text{Divergence of the laser beam}}$$

As a result, the number of resolvable beams (or spots) increases with beam width across the aperture (i.e. lower beam divergence).

Salient equations for a AO modulator are given in the schematic at the end of this document..

Application

AO devices can be used to amplitude modulate or deflect CW or pulsed laser beams, and can be configured to generate a number of time sequential beams, separated in angle.

We manufacture devices working with IR optical powers up to 600W, but in general the average or CW powers range between 100-400W.

The table below gives a number of examples with typical performance figures.
These assume a Gaussian profile input beam.

Optical power Watts	Beam size $1/e^2$ (h x w) Mm	Power density W/mm^2	Mod'n risetime usec	Typical sep'n angle @ center freq mrad / MHz	Spot Res' N No.	Isomet Device Type Series	Optical Insertion Loss @ 10.6um
50	6 x 6	3.5	0.7	77 / 40	22	A	<11%
100	3 x 3	28	0.35	77 / 40	22	C	<5%
200	6 x 6	14	0.7	77 / 40	22	C	<5%
250	7 x 7	13	0.8	77 / 40	25	B	<7%
380	6 x 6	27	0.7	96 / 50	18	C	<5%
450	7 x 7	23	0.8	77 / 40	25	C	<5%
600	7 x 30	7.0	3.5	135 / 70	220	D	<5%

Type A: 1207B-3, 1207B-6
Type B: 1209-7, 1209-1010, DBM1172
Type C: AOM640, 650, 740, DBM1186, M1199, M1208, M1315, D1315
Type D: LS600, LS700

Please refer to the device datasheets for specific characteristics.

Optical Power Guarantees

Isomet are unable to guarantee operation of our Germanium AO devices for optical powers in excess of 200W / 6mm diameter **, essentially because we cannot control the on-site operating conditions. Nevertheless OEM customers are operating at around 25W/mm^2 and there have been no reported damage problems due to A/R coating or bulk crystal failure.

As an extreme example, an AOM640-7 has been tested with a 800W laser for a number of hours (beam dia. 6-7mm). The system was open to the environment. The test time was not extended because of concerns that room dust contamination would burn into the optical surfaces and start the damage process. Thermal lensing was evident.

Longer term examples include the 1209-7 and AOM650 series modulators used in Industrial applications. These modulators operate at 250W+ average optical power from Coherent K250 and K300 Lasers. These systems have worked successfully in the field for many years.

A determining factor in preventing optical damage is the environment. Any contamination that gets onto the optical surfaces is likely to induce optical damage. It is strongly recommended that the AO device (and optics) be installed in a semi-sealed housing with a positive pressure of dry nitrogen backfill.

In certain cases, ZnSe windows have been fitted to the AO device in order to reduce the risk of surface contamination.

**** Optical damage**

Since we have no control over the comparatively harsh operating conditions typical of many high power industrial modulator and deflector systems, we are unable to warranty against surface damage to the optical faces.

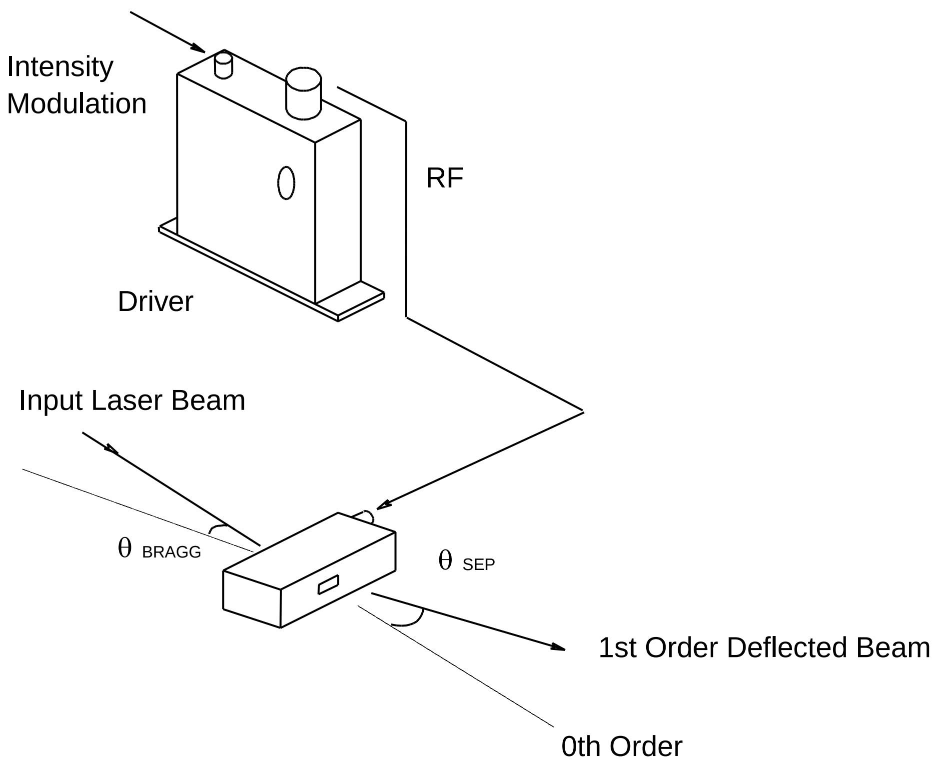
Water cooling

To minimize thermal effects, Germanium devices must be adequately water cooled.
The recommended operating conditions are 20degC at 2litre / minute flow rate.

Unless otherwise stated, Isomet water-cooled modulators and deflectors are manufactured with clear anodized Aluminium case parts. This metal offers significant benefits in terms of low mass and high thermal conductivity. High thermal conductivity is necessary for effective cooling of the AO transducer and absorber faces. However Aluminium is prone to corrosion particularly if other components in the cooling system contain metals such as Copper and Brass.

Corrosion can cause restricted flow of coolant around the AO device case and eventually lead to total blockage and device failure. As a result we strongly recommend the use of an anti-corrosion inhibitor. Please refer to AN1209

Basic AO Modulator Parameters



The input Bragg angle, relative to a normal to the optical surface and in the plane of deflection is:

$$\theta_{BRAGG} = \frac{\lambda . fc}{2.v}$$

The separation angle between the Zeroth order and the First order is:

$$\theta_{SEP} = \frac{\lambda . fc}{v}$$

Optical rise time for a Gaussian input beam is approximately:

$$T_r = \frac{0.65\ d}{v}$$

where: λ = wavelength
fc = centre frequency = 50MHz e.g. RFA250-2
= 40MHz e.g. RFA240-2 / RFA241/ RFA641

v = acoustic velocity of interaction material
= 5.5mm/usec (Ge)

d = $1/e^2$ beam diameter

ISOMET CORP, 5263 Port Royal Rd, Springfield, VA 22151, USA.
Tel: (703) 321 8301, Fax: (703) 321 8546, e-mail: isomet@isomet.com
ISOMET (UK) Ltd, 18 Llantarnam Park, Cwmbran, Torfaen, NP44 3AX, UK.
Tel: +44 1633-872721, Fax: +44 1633 874678, e-mail: isomet@isomet.co.uk
www.ISOMET.com