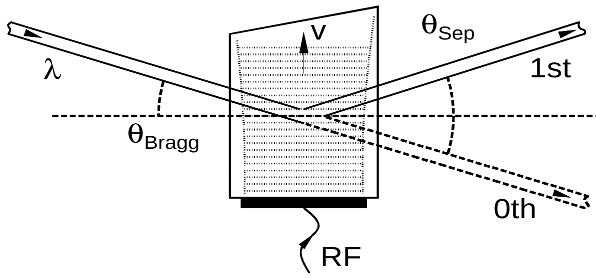
Application Note

AN1101 *June 05*

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, scan angles are in the order of 2-3 degrees 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 at 10.6um 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 higher powers heating due to this 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 100W, thermal lensing should be considered in the system design.

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- Reports from a number of our customers indicate that thermal lensing is controllable if the optical power density is below a figure of around 10W / mm^2 for Model series 1208/1209 and 20W / mm^2 for Model series LS600/AOM600. 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. For optimum performance, the coolant temperature should be less than 20degC at greater than 1litre/minute. Most of the heat is generated from the RF drive but the contribution from optical absorption can be significant when the average 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 attached schematic.

Application

An AO device can be used to amplitude modulate a CW / pulsed laser beam and/or generate a number of time sequential spots/beams, separated in angle.

We have manufactured devices working with input beams powers up to 600W, but in general input powers range between 100-400W.

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

Optical power Watts	Beam dimensions $1/e^2$ (h x w) mm	Power density W/mm^2	Mod'n Rise time usec	Scan Angle mrad	Spot Res N No.	Isomet Device Model	Optical Insertion Loss @ 10.6um
50	6 x 6	3.5	0.7	38.5	22	1207B	<14%
100	6 x 6	7.1	0.7	38.5	22	1208	<6%
200	6 x 12	7.1	1.4	38.5	44	1208	<6%
225	6 x 6	15.9	0.7	38.5	22	1208	<6%
250	7 x 7	13	0.8	38.5	25	1209	<7%
400	4 x 18	14.2	2.1	77.0	130	LS600	<4%
500	7 x 7	26.0	0.8	38.5	25	AOM600	<4%
600	8 x 32	6.0	3.8	77.0	232	LS600-10	<4%

Optical Power Guarantees

Isomet are unable to guarantee operation of our Germanium AO devices for optical powers in excess of 200W**, essentially because we cannot control the on-site operating conditions. Nevertheless OEM customers are operating at around $16W/mm^2$ and there have been no reported damage problems due to A/R coating or bulk crystal failure.

As an extreme example, a 1208-6 has been tested with a 500W 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.

Longer term examples include the 1209-7 and AOM600 modulators used in Industrial applications. These modulator operate at 250W+ average optical power from Coherent K250 and K300 Lasers. These systems have worked successfully for over 3 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.

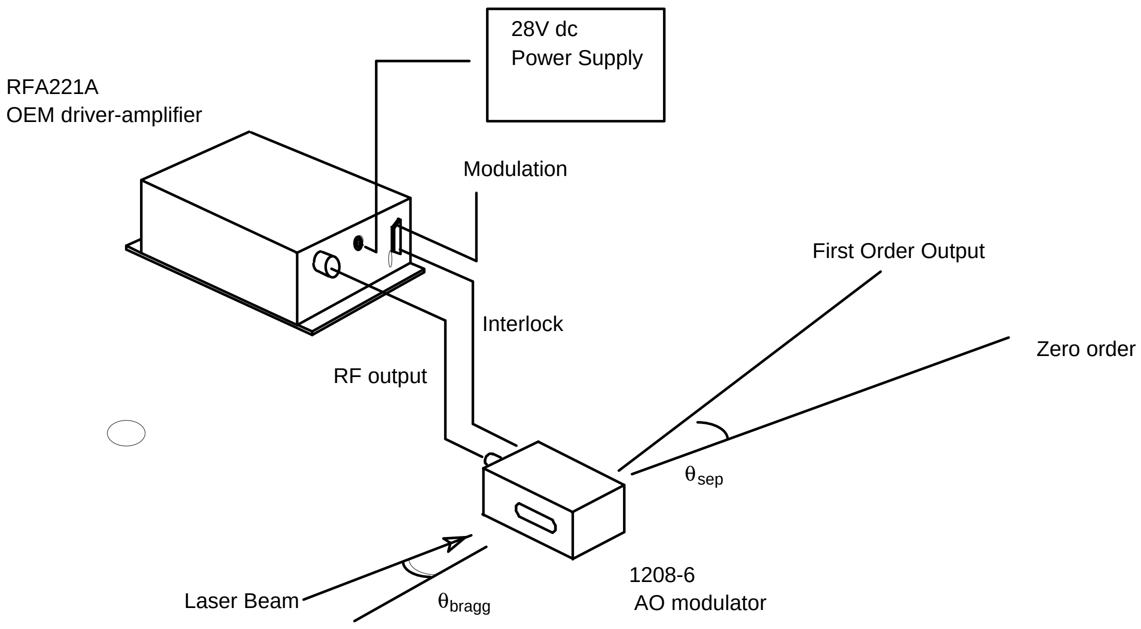
In certain cases, ZnSe windows have been fitted to the AO device in order to reduce the risk of surface contamination.

** 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.

Application Note

Schematic of 1209 Acousto-optic Modulator and OEM drive electronics.



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 output is:

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

Modulation rise time for a Gaussian beam is:

$$T \cong 0.65 \times d/v$$

where :

λ	=	wavelength
fc	=	centre frequency (40MHz)
v	=	acoustic velocity of interaction material (5.5mm/us for Ge)
d	=	beam width along acoustic axis

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