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AN2426 Pulse stretching in AO devices.

Group velocity dispersion (GVD) is caused by index change with wavelength in physical material.

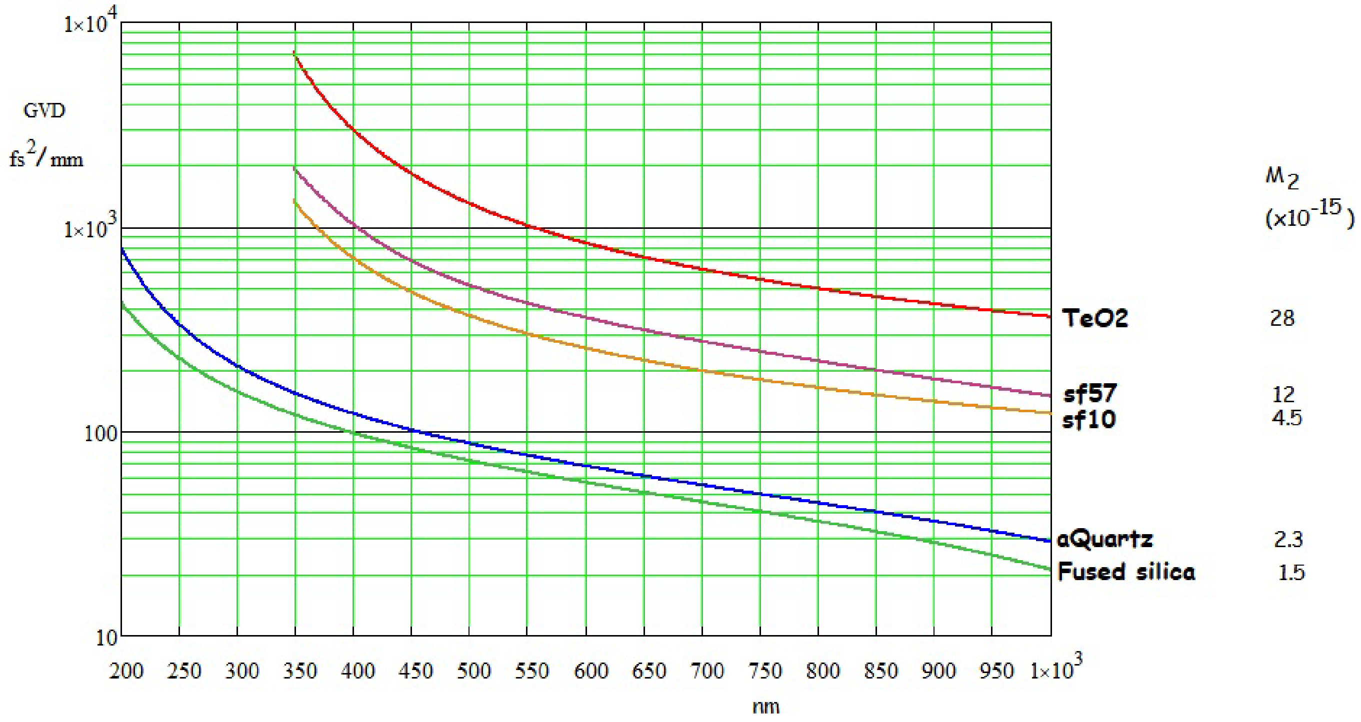
For very short optical pulses (femtosecond region), the spectrum or frequency components will not travel at the same velocity through the material, distorting the pulse and lengthening it.

GVD is defined as:

$$GVD(\lambda) = \frac{\lambda^3}{2 \cdot \pi \cdot c^2} \cdot \frac{d^2 n(\lambda)}{d\lambda^2}$$

c is light velocity in vacuum
n(λ) is material index as a function of wavelength.

GVD data is plotted below for some common AO materials used in Isomet AO modulators, pulse pickers and deflectors. GVD is the characteristic used to determine how the AO crystal medium will affect the duration of an optical pulse traveling through it. This is a key consideration for AO applications involving ultrafast lasers where pulse durations are down in the femtosecond region.



The M_2 figures on right hand vertical axis = the AO figure of Merit at ~1um.

It illustrates one compromise that is required. Low GVD crystals have poor figure of merit which in turn dictates relatively high peak RF drive powers.

Group Delay Dispersion

To determine the temporal distortion effects (pulse stretching) and chromatic dispersion, the crystal optical path length for the AO device of interest must be known.

$$GDD(\lambda) = L \cdot GVD(\lambda)$$

GDD is the group delay dispersion and is the product of the total AO optical path length (L) and GVD. The optical path length information is typically provided on the AO data sheet.

Temporal distortion (Pulse Broadening)

$$T_{out} = T_{in}\sqrt{1 + \left(\frac{2.773 \cdot GDD}{T^2{}_{in}}\right)^2}$$

T_{in} is input pulse duration, fs
T_{out} is output pulse duration, fs
GDD is group delay dispersion, fs^2

Rules of thumb-

1: Where GDD/ T^2_{in} << 1, pulse stretching is minimal

2: Where GDD/ T^2_{in} >> 1, pulse stretching can be simplified to T_{out} = 2.77 x GDD / T_{in}

3: Optical path lengths in typical VIS-NIR AO devices are in the region of 10-25mm.

Example:

M1406-aQ80-1. Quartz crystal, optical path length 20mm

At 800nm, GVD ~44fs^2/mm and GDD = 880 fs^2

For a 100fs input pulse width, the output pulse width = 103fs

For comparison a TeO2 AOM with same path length would stretch the output pulse width to >250fsec.

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Dispersion Compensation using an AOM

A means to create negative GDD would cancel the dispersion and maintain the integrity of the extremely narrow pulse modulation. This can be achieved using prisms, gratings or an AOM.

For an AOM, the spectral frequency components are diffracted at various angles, i.e.,

$$d\theta = \frac{F \cdot d\lambda}{va}$$

It can be shown that as the spectral components after the AOM travel in directions proportional to wavelength, the effect creates a negative GDD.

$$GDD(\lambda) = \frac{-\lambda^3}{2 \cdot \pi \cdot c^2} \cdot \frac{F^2}{va^2} \cdot D$$

F is the frequency in the AOM
va the acoustic velocity
D is the distance from the AOM

When the sum of the positive and negative delay dispersions is zero, the pulse shape is restored.

The required net zero distance D from compensation AOM can be found as,

$$D = L \cdot \left(\frac{va}{F}\right)^2 \cdot \frac{d^2 n(\lambda)}{d\lambda^2}$$

For example, consider TeO2 compensation AOM preceding a TeO2 XY AO deflector with a total optical path length of 60 mm (20mm per AO device). Acoustic velocity is ~678 m/s and in this example, the AOM centre frequency = 100MHz.

In TeO2, the second derivative of index is ~4900*10^8 at 820 nm.
For 90fs laser pulses, the spectrum is 11nm wide.
At 100MHz for the AOM, dθ is 1.65mrad.

The resultant separation distance D from compensating AOM to XY AOD is ~160 cm

This distance could be a potential problem. The aperture of the XY deflectors must be increased to accommodate the angular spread dθ. Increased active apertures mean increased RF drive powers.