Introducing the NIR-MX-LN & NIR-MPX-LN series

The NIR-MX-LN amplitude and NIR-MPX phase are an electro-optical modulators featuring a wide bandwidth of up to 20 GHz. It is designed to operate in between the 980 nm to 1150 nm optical wavelength range. Modulator chip is screened for the wavelengths operation to warranty mono-mode propagation property over the optical $LiNbO_3$ waveguide.

These modulator have become the reference components for many application in the laser application field. .

IXblue has acquired a unique and extensive know-how in the technique used for producing near infrared modulators - typically for the 780 nm up to 1150 nm wavelength range. We present in this document our technological choices and their consequences on the performance of the amplitude NIR-MX and phase NIR-MPX modulators.

Spurious effects in $LiNbO_3$ modulators

We know that the performance of modulators using a $LiNbO_3$ substrate is susceptible to external factors such as optical power - Photo-refractive effect, temperature - Strain-induced effect and electric charge accumulation - Pyro-electric effect.

But what can we do to mitigate these effects ?

Choosing the best crystal cut to minimize the pyroelectric effect

When designing a $LiNbO_3$ modulator, two crystal orientations can be chosen:

The Z-cut modulator - where electric fields are applied along the Z axis - features low insertion losses as well as low $V\pi$. This comes from a high electro-optical efficiency coefficient along the Z axis of the crystal and a better overlap of optical and electrical fields. On the other hand, the pyroelectric effect is very strong and the drift of the modulator - instability of the electro-optical transfer function of the modulator - is very high. Therefore, some Z-cut modulators can become difficult to control with changing environmental conditions (temperature for example).

The X-cut modulator - symmetric structure of the optical waveguides with respect to the electrodes - features slightly lower performance in terms of electro-optical efficiency: $V\pi$ is a little higher and so is insertion loss. On the other hand, the overall behavior of the modulator is better in terms of stability: the drift is very limited, and the pyroelectric effect significantly lower. In other words, the X-cut choice makes it possible to produce modulators that are more stable than what can be achieved using Z-cut.

Most of iXBlue $LiNbO_3$ modulators are based on an X-cut design. We believe the benefit of this configuration – stable insertion loss, low drift – outweighs the slight hit on performance.

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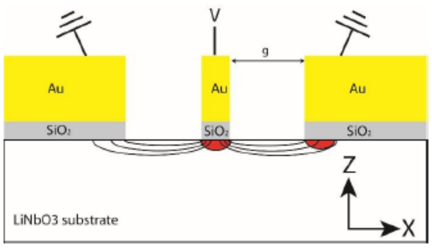

Figure 1a: Z-cut

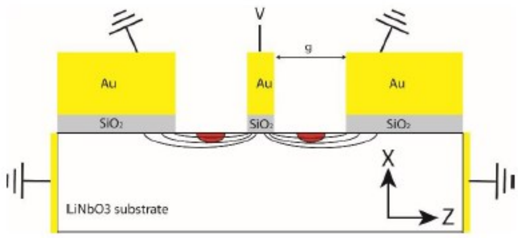

Figure 1b: X-cut

Choosing the best manufacturing process to minimize the photo-refractive effect

Numerous studies have been conducted on the subject of the photo-refractive effect. It has become clear that the optical waveguide manufacturing process in Lithium Niobate substrate is a key factor in effectively mitigating the photo-refractive effect.

Two technologies are used today: the diffusion of Titanium ions in the $LiNbO_3$ substrate (Ti In-Diffusion), and the Annealed Proton Exchange (APE). These two processes aim at locally increasing the refractive index to create the optical waveguide on the $LiNbO_3$ substrate.

Ti In-Diffusion is the most widely used process, mainly for electro-optic modulators used in the telecommunication industry (optical bands O, C and L). It is a reliable process that is fairly easy to implement and yields modulators with low optical losses.

However, modulators produced with Ti In-Diffusion waveguides are more susceptible to photo-refractive effect. This becomes even more critical at shorter wavelengths: in the O-band - at ~ 1310 nm and lower.

When photo-refractive effect appears, the refractive index of the optical waveguide varies in time under the effect of optical power making the performance of the modulator unstable. This translates to higher modulator drift followed with a degradation in optical extinction ratio and an increase in optical losses.

Two $LiNbO_3$ modulators with the same crystal cut and produced with both techniques have been tested for photo-refractive effect when increasing optical input powers. It is clear that the photo-refractive effect appears at much higher optical powers in the version using the Annealed Proton Exchange (APE) process. This makes APE the technology of choice for all modulators operating in the near infrared, even it is it is more complex to implement.

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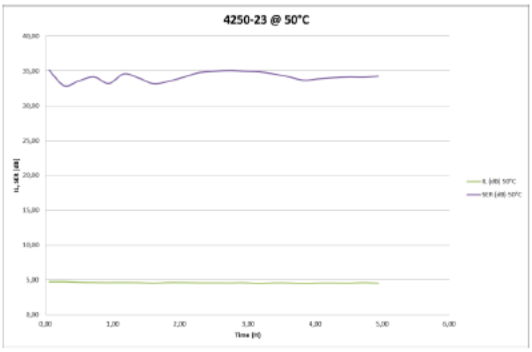
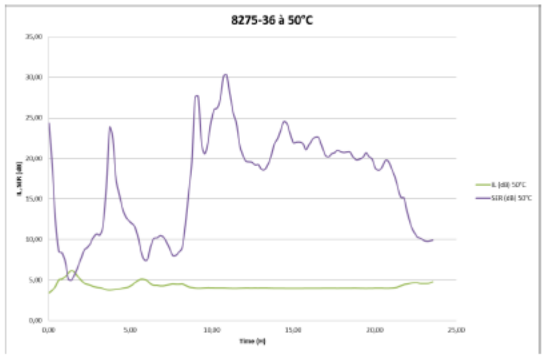


APE waveguide, 80mW



Ti waveguide, 80mW

Figure 2: Measurements of insertion loss and extinction rate for two modulators of identical optical structure, but manufactured with two different processes, APE and Ti-In-Diffusion

Once again, even if the stated performance of a modulator operating in the near infra-red is better with the Ti In-Diffusion technology, the photo-refractive effect could make it un-stable and un-controllable.

Reference: "Comparison of guided wave modulators fabricated on $LiNbO_3$ via Ti and APE", R. A. Becker, Applied Phys. Lett. Vol.43, No. 2, 1983. "

All iXblue modulators operating in the near infrared range are manufactured with the APE process. These modulators offer much better stability because of a higher photo-refractive effect threshold.

Choosing the best $LiNbO_3$ substrate to minimize photo-refractive effect

The photorefractive effect threshold can be increased further by using co-doped $LiNbO_3$ substrates. The added doping helps instantaneous recombination of the free charges that are generated in the crystal by the optical signal therefore providing optical index stability.

The choice of the APE technology, combined with the substrate co-doped $LiNbO_3$, makes it possible to increase the modulator optical power handling prior to trigging photo-refractive effects. This is especially beneficial and necessary for very short wavelengths in the Near Infra-Red window.

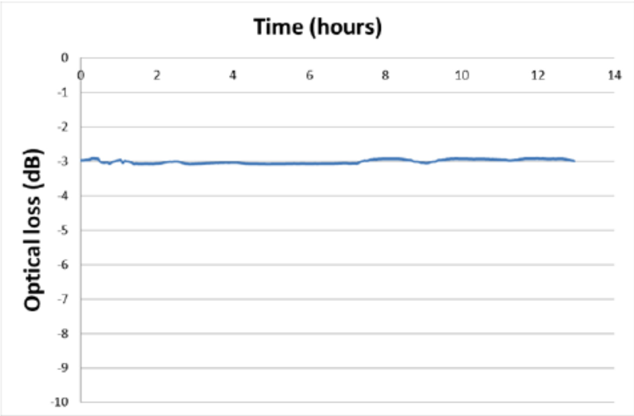


Figure 3: Measurement of the insertion loss stability of the NIR-MX amplitude modulator

Electro-optical effect, bandwidth

IXblue is one of the top manufacturers for very high bandwidth electro-optic modulators used for telecommunications. The demand is mainly in the O, C and L optical bands.

iXblue has developed a 20 GHz (Resp. 40GHz) broadband modulator for optical wavelengths in the near infrared 1 000 nm (Resp. 780 nm, 850 nm, 930 nm) using a specific RF electrode design

The wide electro-optic bandwidth allows the NIR-MX (Resp NIR-MX800) amplitude modulator to generate ultra-short optical pulses with very short rise times (on the order of a few picoseconds).

Also, the RF electrodes are terminated with a 50 Ohm load, which makes it possible to minimize the level of the parasitic electric reflections (S_{11}) and thus improve the efficiency of the electro-optic conversion.

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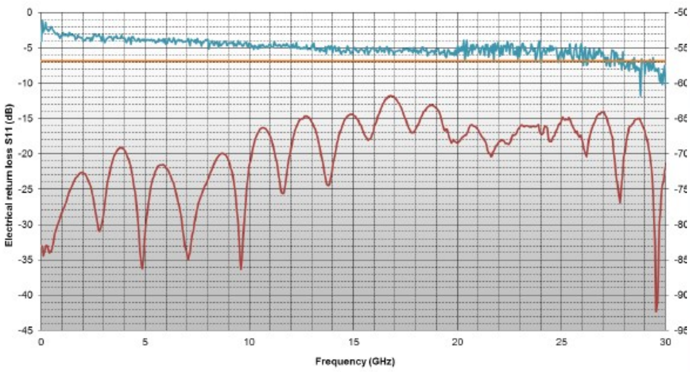

Figure 4a: Parameters [S] of a NIR-MX800-LN-20 modulator

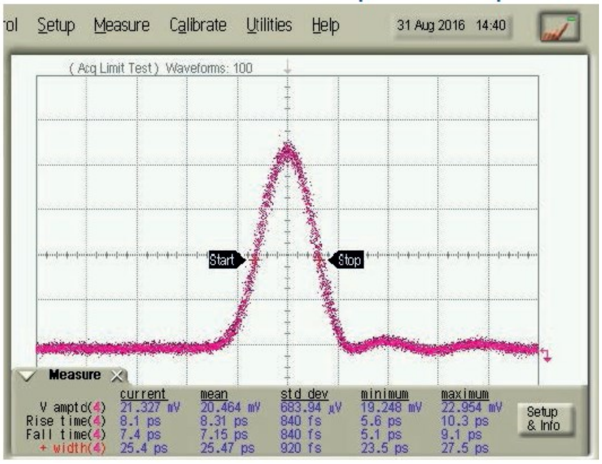

FIG. 4b: optical pulse generated by a NIR-MX800-LN-20 modulator

Extinction Ratio

The APE technology used to manufacture optical waveguides in the near infrared has a double advantage:

• It is effective in preventing the photo-refractive effect in $LiNbO_3$.

• It creates a polarizing waveguide, which further improves the extinction rate (very strongly disturbed by parasitic polarization).

It is therefore possible to manufacture modulators with a very good rate of intrinsic optical extinction. IXblue offers extinction ratios > 30 dB. Chips can be handpicked for best performance.

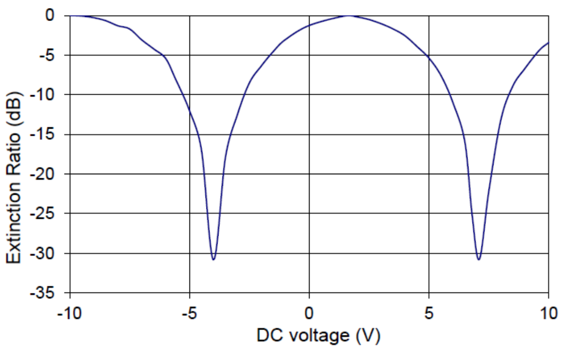

Figure 5a: Measurement of transfer function featuring extinction ratio above 30 dB

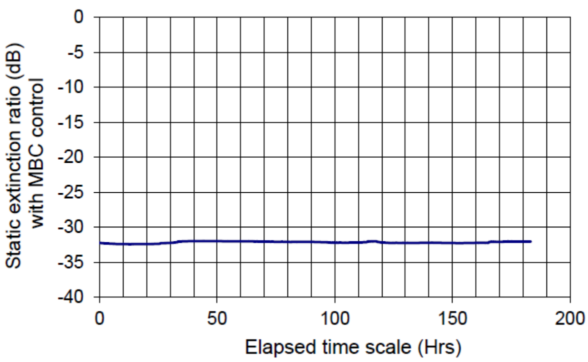

Figure 5b: Stability of extinction ratio over time, NIR-MX with MBC

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