Fast Endless Seamless Dynamic Polarization Controllers Using EEO crystals

INTRODUCTIONS

In fiber optic communication, sensing systems, optical imaging and security, many devices, such as 100Gb/s coherent detection systems, interferometers, and electro-optic modulators, are sensitive to polarization-related impairments. These impairments results from high internal birefringence such as core asymmetry and built in stress, and external birefringence such as twists, pressure, mechanical stress, thermal stress applied to optical fiber links. The induced birefringence changes make polarization related impairments time dependent[1].

A dynamic and adaptive polarization controller is needed to overcome random variations. A dynamic polarization controller can convert any given polarization state to any desired polarization state[2].

Uninterruptible transmission is also critical for dynamic polarization controllers in optical networks. It is necessary that the polarization controller track continuously all changes in polarization without becoming saturated (endless tracking)[2].

High speed is essential for tracking fast polarization variations such as those caused by locomotives passing fibers laid along railway tracks or by ocean waves in undersea fiber trunks. The response time of the dynamic polarization controller for PMD mitigation must be less than 1 ms. In practice, a response time less than 100 μs is required[3].

EEO crystal, an innovative electro-optical crystal, provides a new platform to develop polarization controllers that are fast in response speed, endless in tracking, seamless in dynamic and adaptive control, to overcome the polarization related impairments in optical fiber links.

The main advantages of utilizing EEO crystal over other electro-optical materials for polarization control can be summarized as:

High electro-optic coefficient

One of the biggest advantages of utilizing EEO crystal for polarization control is the super high electro-optical coefficient. The electro-optical coefficient of EEO crystal working in transverse mode is 300~600pm/V. In the polarization control devices, the size of each dynamic waveplate is dramatically reduced and the half-wave voltage needed can be designed to be less than 36V.

Linear electro-optic effect

EEO crystal is non-centrosymmetric material and exhibits the *linear* electro-optic effect, where the refractive index change is proportional to the electric field strength. This linear electro-optic effect of EEO crystal can greatly simplify the polarization control algorithm.

Fast Response

The polarization control devices utilizing EEO crystal are offering fast response in sub-microsecond level. The dramatic increase in speed enables a significant improvement of polarization sensitive devices and systems and helps saving time and money.

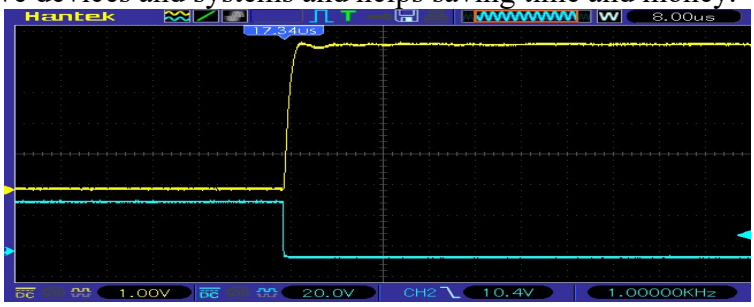

Fig. 1 Demonstration of high speed, rising and falling time <1.5μs

High repetition rate

EEO crystal provides high repetition rate which is required in polarization scrambling devices against rapid SOP (state of polarization) variations in modern fiber optic transceivers, and other systems that deploying coherent detection techniques.

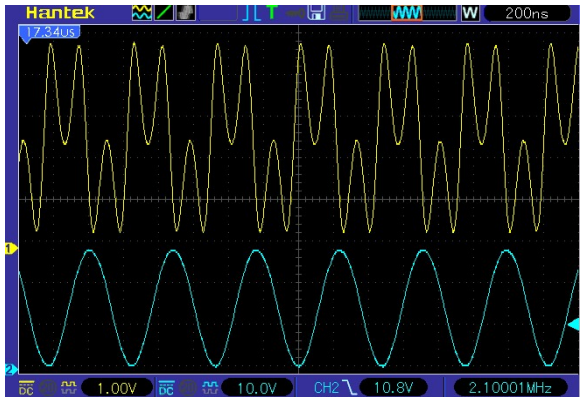

Fig. 2 Up to 2.1MHz modulation rate in 0~2π phase shift range

Low activation loss

Tlow activation-induced loss makes the EEO crystal-based polarization devices ideal for applications in high precision PDL measurement instruments, and in feedback loops for compensating for polarization induced penalties.

All solid-state configuration

The Solid-state structure of EEO crystal-based polarization control devices provide flexibility on arranging and designing the orientation of dynamic waveplates and the number of channels. More components, such as tap, and photodiode (PD), polarizers, and passive waveplates can be integrated in one mechanical package.

Long life time/ High reliability

High reliability of EEO crystal-based polarization controllers come from to the nature of the crystal and special designs of the packaging with no moving parts.

EEO CRYSTALS: ELECTRO-ELASTO-OPTICAL CRYSTAL[4]

EEOptics' EEO crystal is the first practically useful PMN-PT based ferroelectric crystal. The EEO is defined as inverse-piezoelectric "E", Elasto "E" and Optical "O". The unique features are well identified from the combination of inverse Piezoelectric effect, Elasto-Optic effect and pure Electro-Optic effect. The EEO crystal is structurally stable, crystal-clear. It shows very low V_π and great effective E-O coefficient.

EEO crystals have excellent transparency over a wide range of wavelength band, from visible to middle IR. Shown in Fig. 1 is the optical transmission spectrum of EEO crystal wafer with a thickness of 2 mm from 300~7000nm.

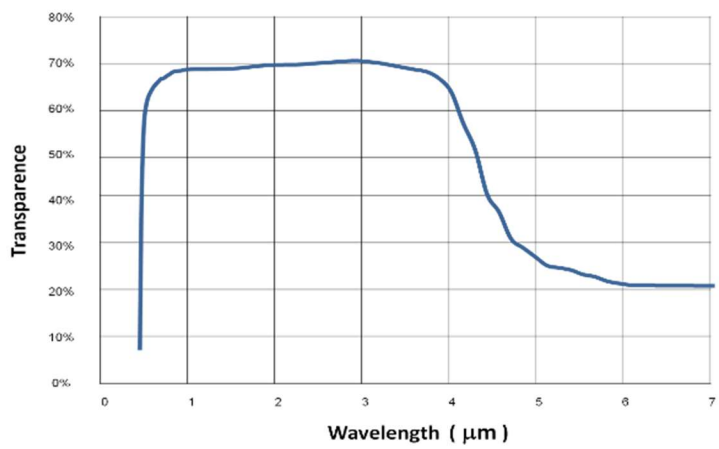

Fig. 3. Transmittance spectrum of EEO Crystals

EEO Crystals exhibit the *linear* electro-optic effect, or ***Pockels effect***, where the refractive index change is proportional to the electric field strength. One important property of EEO crystal is the large EO coefficient, which is 10~20 times higher than LiNbO3 single crystal. Table 1 shows the comparison of EO co-efficiency of EEO crystals and other traditional EO crystals.

Table 1. Physical Property Comparison of EEO Crystals to Traditional E-O Crystals

E-O Crystal	Apparent γ_c	$V_{\pi\,(l=d)}^{T}$ V	V_π^l V
$LiNbO_3$	31	3,030	5,300
EEO Crystal	300~600	80~165	100~150

γ_c Effective (Apparent) E-O coefficient, pm/V
$V_{\pi\,(l=d)}^{T}$ Transverse half-wave voltage (normalized to $l = d$)
V_π^l Longitudinal half-wave voltage

EEO POLARIZATION CONTROLLERS AND APPLICATIONS

One of standard configurations that provide endless and seamless polarization control is shown in Fig. 4. Four EEO crystal plates are used to rotate the income State of Polarization (SoP) and they

are oriented at 45º, 0º and 90º, and -45º, respectively, with respect to 0º orientation. By applying the voltage to a plate, there is birefringence generated whose magnitude increases linearly with the applied voltage. Thus, the retardation angle in each plate is a linear function of the applied voltage.

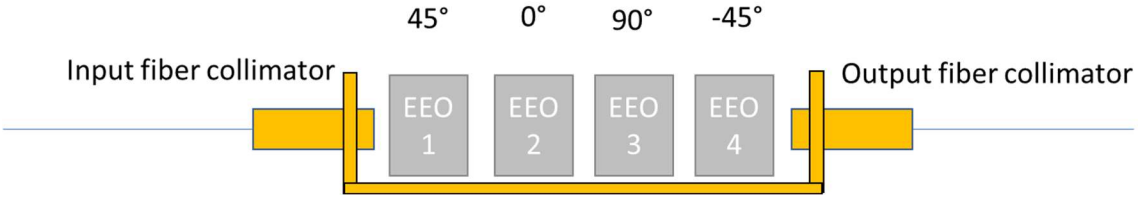

Fig. 4 Configurations of EEOptics' high speed polarization controller

Theoretical, two dynamic retarders placed 45° with respect to each other would be capable of changing the input SoP to any polarizations. In circumstances when one retardation-plate reaches π phase shift or out of range, there are two options for subsequent operations: either further applying voltage beyond V_π to maintain system compensation or reducing voltage to zero and staring over again. Applying higher voltage than V_π voltage would be at the price of higher activation loss while rewinding to zero voltage would leave the system an uncontrolled period, which is not acceptable. Therefore, the third dynamic retarder is added to help the rewinding process; that is, when the voltage on the rewinding plate is reduced, the extra plate would be biased up to realize a seamless and endless control. The fourth retardation plate is added to provide additional offset, increase error tolerance and improve system stability.

With free-space micro-optic design, additional active and passive optical components can be easily aligned in the optical path and integrated in the same mechanical package in a compact way. Some applications require six distinctive SoPs for better calibration accuracy. And some applications need a quarter waveplate, one or two polarizers, a tap mirror and one or two photodetectors depending on the system control algorithms.

APPLICAITONS

Without any feedback control loop, by adjusting amplitude and frequency of each EEO elements, EEO polarization controller can be used in polarization scrambling. Connect/integrate a feedback loop, EEO polarization controllers can be used in PMD compensation, polarization optimization, polarization-induced crosstalk reduction and PDL characterization and compensation.

References:

1. Chao Yeh et al, Overcoming polarization impairment. Fiberoptic Product News (October 2000)
2. Kazuhiro Ikeda, Takeshi Takagi, Tatsuya Hatano, Hajime Kazami, Yu Mimura and Hiroshi Matsuura, "Endless Tracking Polarization Controller", Furukawa Review, No. 23, 2003, p. 32~38
3. Combat Polarization Impairments with Dynamic Polarization Controllers, Application guide, General Photonics Corporation
4. Pengdi Han, Weiling Yan, and Qiushui Chen, "Electro-Elasto-Optical Properties of EEO Crystals (PMN-PT based relax ferroelectric Crystals) by Special Modifications" CLEO: Science and Innovations 2018