ISSN: 1813-162X
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

Investigation the Performance of Electro-Optical AC Voltage $LiNbO_3$ Sensor Based on Pockels Effect

Shahir Fleyeh Nawaf
Electrical Engineering Department, Tikrit University , Salahuddin Province, Al-Qadissiay, P.O. Box 42, Republic of Iraq.

ABSTRACT

In contrast to conventional voltage sensor technology (e.g., inductive voltage transformers or capacitive voltage transformers), optical sensors have inherent and advantageous features, such as wider bandwidth, larger dynamic range and lighter weight. The aim of this work is to implement an AC voltage sensor based on Pockels electro-optic effect in $LiNbO_3$ crystal. The research has been conducted in two ways .The first way is the installation tested uses external electrodes and a He-Ne laser as a light source, whereas the second way is by using the direct voltage application to the metalized sides of the $LiNbO_3$ crystal built into an optic cell. Results of both tests shows that by using the direct voltage application to the metalized sides of the $LiNbO_3$ crystal built into an optic cell led to better repeatability of voltage measurements and corresponds to more realistic conditions.

Keywords : Pockels electro-optic effect, He-Ne laser, AC voltage sensor

تحقيق أداء متحسس نيوبات الليثيوم الكهروضوئي لفولتية التيار المتناوب باعتماد تأثير بوكل

الخلاصة

ان المتحسسات الكهرووضوئية تتميز بخواص ايجابية عديدة بالمقارنة مع تقنية متحسسات الفولتية التقليدية والمتمثلة بمحولات الفولتية الحثية منها والسعوية وذلك لكونها ذات عرض حزمة اوسع و مجال ديناميكي اكثر و وزن اخف . يهدف هذا البحث الى اختبار متحسس فولتية التيار المتناوب والذي يعتمد عمله على مبدا تأثير بوكل الكهروضوئي على بلورة نيوبات الليذيوم . تم اجراء البحث بطريقين: الاولى بتسليط فولتية على الخلية الضوئية من خلال اقطاب خارجية مثبتة عليها و التي ينفذ من خلالها الضوء المنبعث من مصدر ليزري متكون من عنصري النتروجين والهليوم (He-Ne) اما الطريقة الثانية فهي تجهيز الفولتية مباشرة على طرفي الالواح المتكونة من بلورة نيوبات الليثيوم ، النتائج العملية اظهرت صلاحية استخدام هذا المتحسس في قياس الفولتية ، ومن خلال مقارنة نتائج الطريقتين تبين بان الطريقة الثانية افضل والتي يتم فيها تسليط الفولتية مباشرة على بلورة نيوبات الليثيوم في الخلية الضوئية وذلك لاعطائها نتائج اكثر دقة واستقرارية لقياسات الفولتية .

الكلمات الدالة: تأثير بوكل الكهروضوئي ، ليزر الهليوم والنيون ، متحسس فولتية التيار المتناوب

List of abbreviations

TEM: Transverse ElectroMagnetic
$LiNbO_3$: Lithium Niobate

INTRODUCTION

Appearance of lasers and new technologies in crystal production lead to first theoretical and experimental works associated with electro-optical modulation and its applications in measurement.Current and voltage measurements in high voltage power and industry facilities are of essential importance for normal and safe functioning of the system. The aim of measurements is not only to quantify provided energy but also to follow all parameters of the given system, controlling the work of the system, noticing anomalies and protecting parts of the system from damage or destruction. These measurements are performed by specifically designed sensors [1].

Pockels electro-optic effect, produces birefringence in an optical medium induced by a constant or varying electric field. It is distinguished from the Kerr effect by the fact that the birefringence is proportional to the electric field, whereas in the Kerr effect it is quadratic in the field. The Pockels effect occurs only in crystals that lack inversion symmetry [2] such as lithium niobate or gallium arsenide and in other non Centro symmetric media such as electric-field poled polymers or glasses. So this research will be concentrate on the Lithium – niobate as one of the most significant electro-optical materials with rather wide spectrum of applications in the field of optics. This is mostly due to its exceptional electro-optical, opto-acoustical, piezoelectric and nonlinear properties [3].

$LiNbO_3$ is a material that can be created with relatively high purity and low price. The crystal is chemically very stable and in addition, not hygroscopic which is of great use in practical implementations. The mechanical stability is also good. Because of these properties and high electro-optical quotients, this material is widely used for optical modulators and Q-switches for lasers[4] .It is also used in nonlinear optics, nonlinear oscillators, frequency mixing and generation of higher harmonics. The basic idea of the AC sensor realization is that it is based on transverse electro-optical modulation in $LiNbO_3$. In comparison to longitudinal electro-optical modulation, transverse modulation is simpler for application, since it does not require optically transparent electrodes, thus solving the problem of creating a relatively homogenous electric field in the crystal along the direction of light propagation [5].

LITERATURE REVIEW

Some researches have been conducted about the opto-electrical devices as following:

- As early as the end of 1980s, Researchers from British Columbia University in Vancouver described two integrated opto-electrical devices whose optical output was modulated by applied electric field. The first of these devices was an integrated high-voltage sensor based on Mach-Zehnder interferometer with capacitive voltage divider. The sensor was made in y-cut lithium-niobate [6].
- A new work by Feng Pan , Xia Xiao, Yan Xu and Shiyan Ren in 2011 explored the model of an optical sensor based on transverse Pockels effect on the BGO crystal (Bi4Ge3O12). This sensor has good linearity and accuracy performance which obtained for AC voltage measurement[7,2].

RESEARCH METHODOLOGY

Research has been conducted in two parts,theoretical and practical parts.

Theoretical part

- The circuit consist of the following parts: The crystal which has the dimensions of 6x6x30mm , with wide-range antireflective. layers (500-100nm) applied to the sides perpendicular to the z-axis of the crystal.
- Light source: As a light source we used a He-Ne laser (λ=632.8nm), with 1mW power.
- Polarizer and analyzer : As a polarizer and analyzer, commercially available polarizing films were used.
- Detector: As detector, we use a photodiode, connected in the circuit with a transimpedance amplifier.

After the experiments with the He-Ne laser, we thought of a more compact measurement configuration to serve as a basis for developing an AC sensor. We tried to install a configuration that fits more to real conditions. Therefore, we decided to install a specifically designed electro-optic cell in which we would monitor a light source, polarizer, λ/4 platelet (or a retarder film), the $LiNbO_3$ crystal, analyzer and photo detector. This cell also allows attaching AC voltage supply to the crystal and active components – the light source and the detectors.The central part of the electro-optic composed following:

- Upper carrier.
- Rear L-carrier.
- Crystal.
- Conductive wire.
- Front L-carrier.

- Retarder film.
- Photodiode-housing.
- Polarizing film.
- Led housing.
- Lower carrier .

The first step in mounting is placing the crystal with bonded conductors onto L-carriers. After this we place and fixate the bumper onto the lower carrier. This serves as a rail onto which L-carriers are placed with the crystal. Then the upper carrier is placed and fixed on top. This forms the central part of the cell, after which cylindrical housings are placed on the rear and front parts for the photodiode and led [8] **.**as shown in fig.(1).

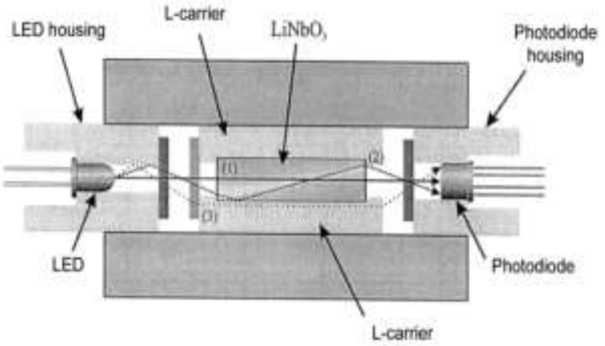


Fig.1 Vertical section of the photo-optic cell [9]

FUNCTION of the CIRCUIT

The transmitted light through the crystal along the optical axis. Two lateral sides of the crystal have been coated with metal layers (gold and chrome alloy) as shown in fig.2.

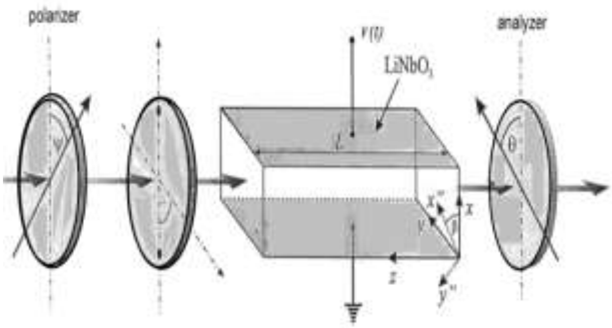
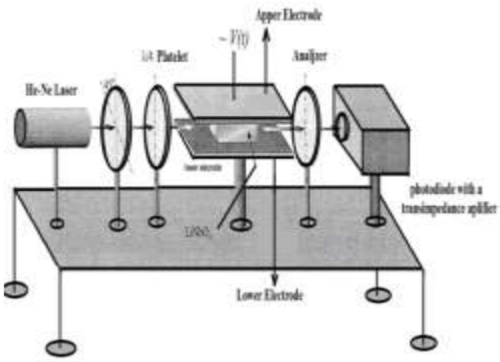


Fig.2 Basic parts for implementation of sensor

This will serve as electrodes to which voltage will be applied. So ,between this two lateral sides will rise an electric field (E)in the crystal along the x-axis. Fields in x-direction change the indicatrix compared to y-oriented fields[9]**.** The all used optical components are fixed on an optics desk. The laser emits linearly polarized light in basic TEM_{00} mode[10], while the divergence angle is 1.3 mrad.. $LiNbO_3$ crystal is placed between two plain metal electrodes monitored on a carrier made of insulators. Between these electrodes were also placed acrylic plates which give additional mechanical support to the entire structure. The basics of this implementation are shown in fig.(3).

Fig.3 Experimental setup for the $LiNbO_3$

Fig.(4) shows a scheme of the



experimental setup with He-Ne laser and instrument connections. The purpose of this setup is to achieve the following two functions:

- The lower electrode serve as mechanical carrier for the crystal.
- The surfaces of both electrodes are in mechanical contact with metalized surfaces of the crystal. this will help to create a homogenous electric field in the crystal, through the application of voltage to the electrodes. The voltage is applied from an autotransformer attached to the grid voltage which have an out put voltage of about 280 which corresponds to the amplitude of AV voltage of 389.2V. This is enough to record the relevant part of the transfer function in which there will be no distortion of output voltage signal[11]**.** We use a photodiode As a detector which connected in the circuit with a transimpedance amplifier, so that.
- The output voltage is proportional to the input light. This voltage as well as the driving AV voltage were monitored on an oscilloscope. In addition, two digital.

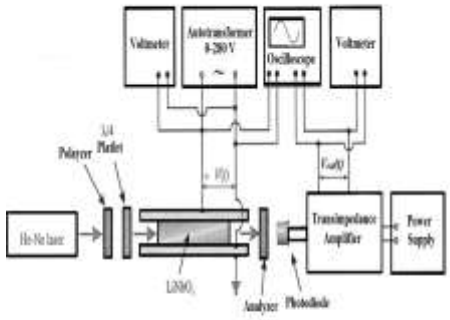


Fig.4 Scheme of the experimental setup with He-Ne laser and instrument connections

- Voltmeters were used –one for input, and one for output voltage measurements. Preliminary measurements with He-Ne laser were conducted in order to record the calibration characteristic for effective values of signals, based on measured values $V_{out}{}^{AC}{}_{eff}$ and $V_{out}{}^{DC}{}_{eff}$ and their ratio S_{eff}[12].

PRACTICAL PART

After setting all the components in their places, connecting the power source and measuring devices, as well as optimizing the positions of optical components, measurements were conducted. The measurements are shown on the fig(5). Some minor discrepancies are noticed between some characteristics. To correct this we determined the relative standard deviation of the measured values. For that purpose, each of the characteristics was approximated by the following polynomial[13]:

$$y_{i(x)} = a_i x + b_i x^2 + c_i x^3 + d_i x^4 + e_i x^5$$

where i represents a corresponding series of measurements.

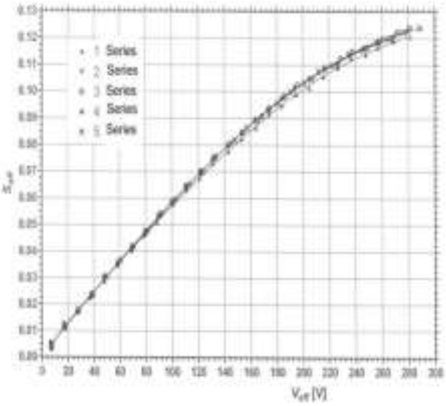


Fig.(5). Experimental values of the calibration Seff for effective values of the signal.

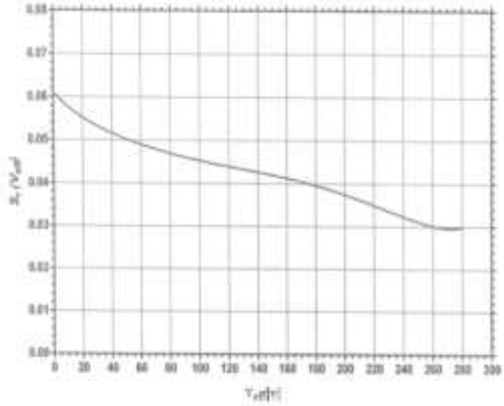


Fig.(6) Relative standard deviation characteristics for effective values for for the optic cell.

The relative standard deviation are shown in fig.(6).

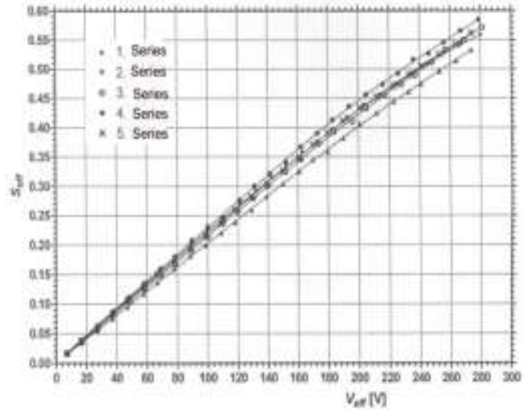


Fig.7 Experimentally attained calibration characteristic characteristics for effective values for the optic cell.

RESULTS and DISCUSSION

After installing the photo-optic cell, a

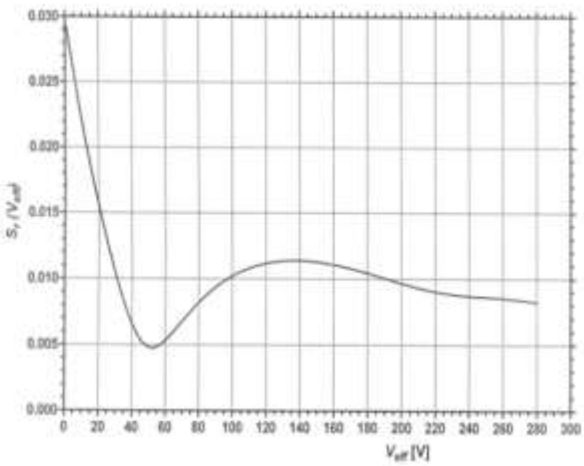


Fig.8 Relative standard deviation of the characteristic measured calibration.

and the input AC voltage were monitored on the oscilloscope, while the effective value of the input voltage and the AC value of the output voltage were measured by voltmeters as shown in fig.(7).

- An experimental setup of the $LiNbO_3$ crystal based sensor was installed with a He-Ne laser. The calibration characteristic showed a noticeable deviation for measurement series.
- A more advanced and more realistic installation was tested, with a photo-optic cell. This showed a much better repeatability of measurements than with the He-Ne laser. Also, the shape of the calibration characteristic resembles a theoretically anticipated graph. The results confirm the correctness of direct application of AC voltage onto metalized surfaces of the crystal.
- One disadvantage of the optical cell was noticed – the measured values of AC output and DC output voltage ratio were smaller than those measured in the setup with the He-Ne laser. This can be explained by the divergence of the light beam of the used diode.

CONCLUSIONS

Current and voltage measurements in high voltage power and industry facilities are of essential importance for normal and safe functioning of the system. Appearance of lasers and new technologies in crystal production lead to first theoretical and experimental works associated with electro-optical modulation and its applications in measurement. In this work we suggested a setup for a $LiNbO_3$ crystal-based electro-optic sensor. This included an experimental installation of the system on an optical table, first with a He-Ne laser, and afterwards a more realistic installation with an optic cell. The coherence of the monochromatic light of the He--Ne laser provides a modulation depth close to the one we expected. However, the use of external electrodes showed lowered the intensity of the field in the crystal, mainly due to the air gaps in the contact areas. Theoretically, the use of external electrodes is possible but strict attention must be paid to the contacts. Based on the measurements and the existence of the air gaps, we decided to test an installation with built-in electrodes, through design of an optic cell with all necessary electrical and optical components. In contrast to the precious setup, here we used a diode as a light source, and the voltage was brought directly to the metalized surfaces of the crystal. The results for this installation showed a much better repeatability of measurements, and the shape of the calibration graph was in correspondence with the expected theoretical form. However, the use of the diode light source brought divergence and resulted in lower modulation depth, therefore a blend should be used to decrease the divergence of the light beam.The suggested configuration of an electro-optic AV voltage sensor based on Pockels effect is relatively easy to install, and can be made by discrete optical components, and it does not require integrated technologies, which would demand additional equipment.

REFERENCES

1- Pena-Lacona, F.G. Mosino, J.F. Filippov, An electro-optic fibre sensor with double pass configuration for measuring AC voltage, Measurement science and technology, 2004.

2-Feng Pan * Xia Xiao, Yan Xu and Shiyan Ren, An Optical AC Voltage Sensor Based on the Transverse PockelsEffect, ISSN 1424-8220, www.mdpi.com/journal/sensors2001 1

3-Karsten Buse, Some Properties of LithiumNiobateCrystals, University of Bon.

4-Bohnert, K.; Gabus, P.; Kostovic, J.; Brandle, H. Optical fiber sensors for the electric power industry. Opt. Laser. Eng. 2005.

5-J.F. Nye – Physical properties of crystals, Oxford University Press, Oxford 1985.

6- Dieter H. Jundt, M. Fejer, Robert L. Byer, Optical properties of lithium-rich niobate fabricated by vapour transport equilibration, IEEE Journal of Quantum Electronics, Jan. 1990.

7- Changsheng Li, Xiang Cui, Toshihiko Yoshino, Optical electric power sensor by use one bismuth germanate crystal, Journal of Lightwave technology, vol 21, May 2003.

8-Dragan K. Stanković, Fizičko tehnička merenja, Beograd 1997.

9- Adam Joseph Iverson, Electro-optic Pockels cell voltage sensors for accelerator diagnostics, Bozeman, Montana, 2004.

10- López-Higuera, J.M. Handbook of Optical Fibre Sensing Technology; Wiley: New York NY, USA, 2002.

11- Yibing Zhang, Novel Optical ensors for High Temperature Measurement in Harsh Environments, Blacksburg Virginia, 2003.