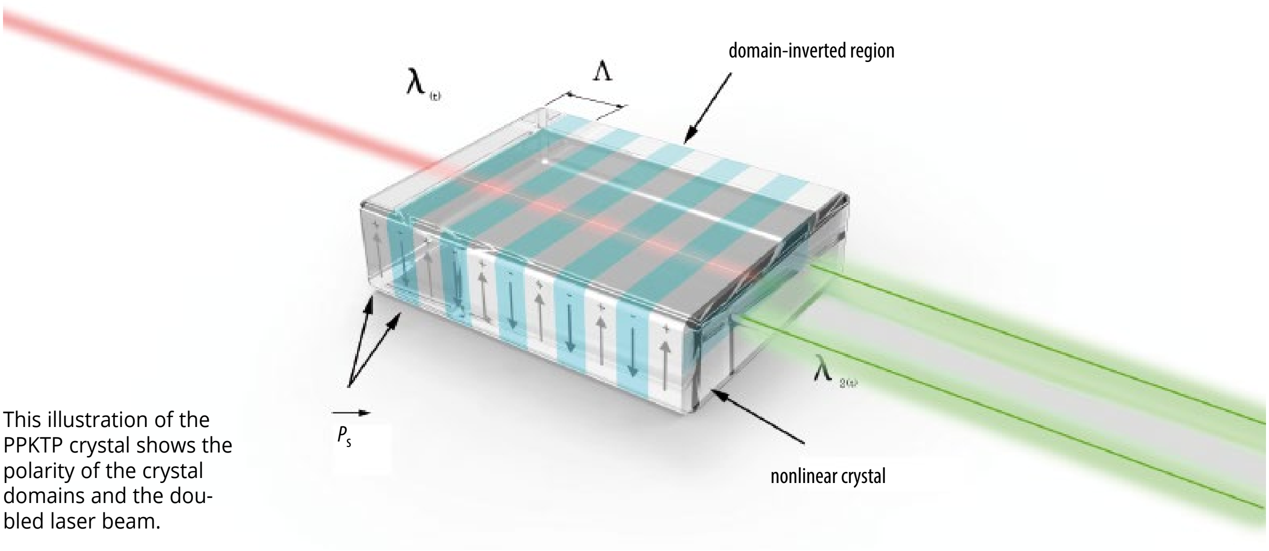
PPKTP Applications: Quantum Encryption

How can entangled photon pairs be produced for quantum experiments or even communication?

Yehiel Plaut



This illustration of the PPKTP crystal shows the polarity of the crystal domains and the doubled laser beam.

Source: Raicol Crystals

Quantum encryption is also known as quantum cryptography, or quantum key distribution (QKD). It is an application in the field of communications, whereby quantum mechanics is used to encrypt messages on single photons, so that unintended recipients cannot read the messages. Quantum encryption allows two parties to establish private encryption keys in an extremely secure manner.

A major advantage of quantum encryption is that data encoded in a quantum state, through quantum encryption, is impossible to copy or read. If a third-party attempts to copy and read a quantum-encrypted message, the data's quantum state will be changed. This is due to the quantum no-cloning theorem [1], which states that it is impossible to identically copy an unknown quantum state without causing an irreversible alteration in the quantum state. This characteristic makes quantum encryption highly secure, and resistant to interference from third parties. Developing a network based on quantum encryption requires careful attention to security, design, and architecture [2].

PPKTP is a nonlinear material made from periodically-poled potassium titanyl phosphate (KTP). This poling technique was patented by Raicol Crystals, together with Tel Aviv University. It is most commonly used for nonlinear frequency conversion.

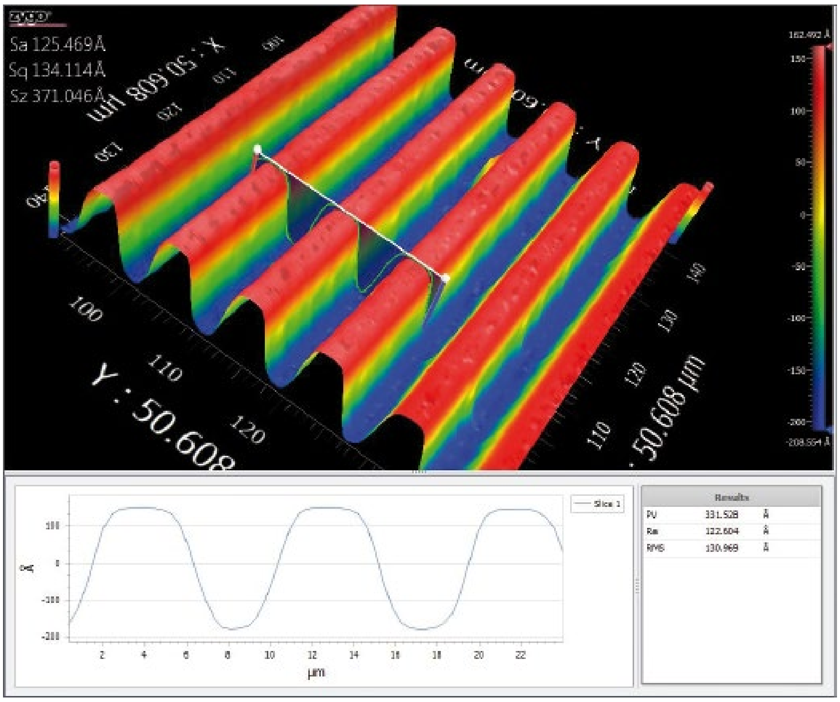
PPKTP is also used in quantum encryption systems that are based on photon entanglement technology. These systems use spontaneous parametric down-conversion (SPDC), a process through which one single photon of higher energy is converted into an entangled pair of photons of lower energy [3]. The SPDC process can be best achieved through the use of a PPKTP crystal set. The entangled photon pair is then used for the generation of secure encryption keys. This is explained further in the following real-life studies.

PPKTP-based quantum encryption in practice

The Ent QKD system

The 'Ent QKD system' [2] – which stands for 'entanglement-based QKD', developed by an Austrian-Swedish consortium, uses quantum entanglement to generate secure network keys. This system uses a PPKTP crystal set. Using the classic cryptography placeholder names Alice and Bob, let's explore how the system works.

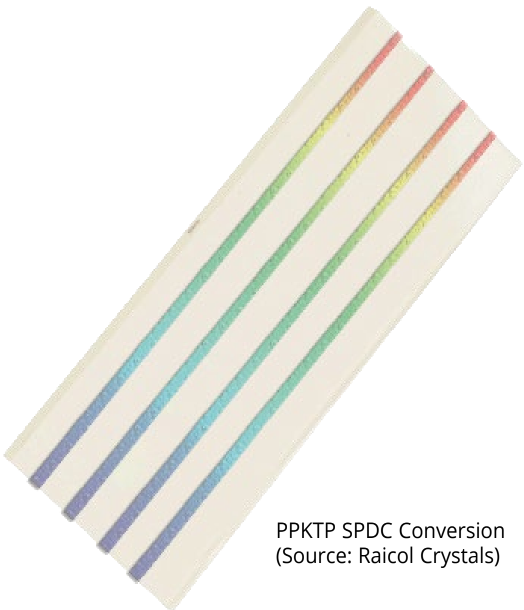
At Alice, the asymmetric source produces two photons of different wavelengths through spontaneous parametric down-conversion in a PPKTP crystal set. In this case, the wavelengths of the resultant photons are 810 and 1550 nm. The 810 nm photon is measured at Alice, through a passive polarization



This simulation of the PPKTP crystal shows the polarity of the crystal domains and the laser beam doubled through the crystal. (Source: Raicol Crystals)

analyzer, and detected by four avalanche photo diodes. Meanwhile, the 1550 nm photon travels down the quantum channel to Bob, where it is registered in a similar manner, using a passive polarization analyzer and avalanche photo diode detection. The polarization measurement results are then processed by onboard electronics and forwarded to an external computer, where the secure key is generated. Various stabilization modules are used to ensure long-term key exchange stability, maximizing photon detection rates and automatically correcting polarization drifts due to environmental and other factors.

This particular QKD device setup is the first 'Ent system' that can operate long-term without requiring user intervention.



PPKTP SPDC Conversion (Source: Raicol Crystals)

Satellite QKD

Direct communication across global distances, up to 1,000 km, require satellites equipped with high-quality optical links to achieve ultralong distance quantum communication as opposed to ground-based QKD systems (non Ent-QKD type), which are limited to around 100 km. In satellite QKD, a satellite establishes independent secret keys with individual ground stations and common keys for a pair of ground stations to communicate with each other. Satellite QKD systems often use DV-QKD (discrete-variable quantum key distribution), which can be achieved through entanglement-based QKD. This requires the generation of polarization-entangled photon pairs based on the SPDC process described above, using PPKTP. As with the Ent QKD system, comparing polarization state measurements for photons at both Alice and Bob provide security.

Quantum entanglement in satellites

PPKTP has been used – among other areas of research – in quantum entanglement. A team of physicists in China recently managed to send intertwined quantum particles over an impressive 1,200 kilometers from a satellite to ground stations, beating world records. This is an important step towards the development of ultrasecure communication network possibilities, and maybe even a space-based quantum internet in the future [4]. The system used by the physicists consisted of a space borne entangled photon source, a continuous-wave laser diode with a central wavelength of 405 nm, and a linewidth of ~160 MHz used to pump a PPKTP crystal inside a Sagnac interferometer. Under a pump power of ~30 mW, the source emitted 5.9 million entangled photon pairs per second [5].

Company

Raicol Crystals

Raicol Crystals manufactures non linear electro-optic crystals for laser systems in the space, aviation, and pharma industries. The company manufactures RTP and KTP crystals – potassium titanyl phosphate, LBO, BBO – in a unique, patented process. Founded in 1995, the company's innovative, state-of-the-art production site includes about a hundred systems for growing crystals in clean rooms, an advanced development department, and crystal coating machines.

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Containing a 15 mm long, periodically-poled KTP crystal, the QES2 source is capable of producing approximately 10,000 photon pairs / sec / mW of pump light. An internal temperature controller ensures that the crystal's temperature is maintained to within ±0.1 °C. This allows a degenerate, non-degenerate signal, and an idler photon production depending on crystal temperature. (Source: Qubitekk)

PPKTP is the only material that allows generation of photon pairs in the quantity needed to conduct an experiment of this kind [6]. It has also been used for ultrafast laser applications, such as to produce an efficient pulse-shortening mechanism with pulses as short as 2.8 ps [7], and for high repetition rate optical parametric oscillators [8]. In addition, multiple research papers [9] have shown that PPKTP crystals demonstrate very efficient second-harmonic generation (SHG) [10] at several wavelengths [11].

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Author

Yehiel Plaut joined Raicol Crystals in 2016 as vice president sales and marketing. Previously, he led the sales and marketing teams at Ophir / Newport Corporation and at 3M for more than twenty years. Yehiel possesses extensive experience supporting customers in the electro-optics and laser markets.

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