NEWS RELEASE

NTT

NIPPON TELEGRAPH AND TELEPHONE CORPORATION

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Successful preparation of KTN crystals with the highest reported electro-optic effect and the potential for providing a great improvement in optical device performance

Nippon Telegraph and Telephone Corporation (NTT) has successfully prepared KTN crystal ($KTa_{1-x}Nb_xO_3$) with the highest electro-optic effect (*1) ever reported. In addition, NTT has developed a film growth and a lithographic techniques for KTN crystal that can be used to fabricate an optical waveguide with excellent optical transmission performance. An optical switch using these KTN waveguides had a low driving voltage less than 1/10 that of conventional optical switches, and this result clearly shows the excellent potential of KTN crystal in terms of optical device performance.
By using these KTN crystals, it should be possible to fabricate optical modulators and optical switches with a driving voltage one order lower than that of conventional optical devices. This will provide a way to develop the next generation of highly functional devices.

KTN is a transparent optical crystal composed of potassium, tantalum, niobium, and oxygen. The first KTN crystal was synthesized in the 1950's and is well known as a crystal with a very large quadratic electro-optic effect (Kerr effect), which determines device performance. However, KTN crystal has been considered an impractical material because it was difficult to grow.

NTT Photonics Laboratories found that precise temperature control is essential in order to grow a large crystal, and they successfully prepared 40 mm square KTN crystals, which is a practical size. The electro-optic coefficient of these KTN crystals is about 600 pm/V, or 20 times larger than that of conventional $LiNbO_3$ (*2). This coefficient means that an improvement in device performance of at least one order can be expected by using this crystal. In addition, NTT fabricated an optical switch whose driving voltage is only 1/10 that of conventional switches.

<Background>
In recent years, the explosive growth in trunk line capacity has largely ended and the goal is now large-capacity and highly functional metro or access networks. In order to achieve this goal, the size and power consumption of optical devices must be reduced and their functionality increased. Of these devices, optical modulators and optical switches made of conventional $LiNbO_3$ materials are especially important for the networks . However, these devices have problems in terms of their large size and relatively high driving voltage resulting from the small electro-optic effect of the $LiNbO_3$ material. Therefore, attention has been drawn to the development of novel materials with a larger electro-optic effect with a view to overcoming these problems.

In addition, in the near future highly functional materials are expected to be used to realize high-speed and highly integrated optical signal processing devices for network innovation.

<Technological points>

<1>Technology for growing large and high quality KTN crystals (Fig.1 and 2)
NTT successfully prepared the largest KTN crystals ever grown (40 mm square X 30 mm long) by optimizing the growth conditions and achieving precise temperature control. This crystal is at least 20 times larger than a conventional $LiNbO_3$ crystal (Fig.3).

<2>Waveguide fabrication technology (Fig.4)
NTT have established KTN crystal films on substrates prepared from bulk crystals by using Liquid Phase Epitaxy (LPE) (*3). High quality KTN films with a controlled thickness of 5-10 micrometers for waveguide fabrication can be prepared by controlling the growth rate and suppressing any temperature fluctuation on the growth surface. This makes it possible to fabricate low-loss waveguides with a loss of 0.5 dB/cm (*5) by using the dry etching technique (*4). Complex optical circuits can be fabricated with these technologies.

<3> Demonstration of optical switching (Fig.5)
A Mach-Zehnder interferometer (*6) was constructed using KTN crystal waveguides and a silica glass waveguide. An optical switch is operated by applying a voltage to electrodes prepared on the KTN waveguide surface. Optical switching was measured that had a very low voltage of 1.3 V, which is about 1/10 the voltage needed with the conventional device. Polarization independent operation was also confirmed (*7) and this is indispensable for optical switches. NTT has therefore achieved an optical switch with the lowest driving voltage yet reported and polarization independent operation.

<Prospects>

In order to develop highly functional optical signal processing devices, NTT plans to proceed with large crystal growth and large-scale optical circuit fabrication with a view to demonstrating the very high potential of KTN crystals (Fig.6).

<Technical terms>

*1: Electro-optic effect
A refractive index change results when an electrical field is applied to a material. The effect of the linear relationship between this refractive index change and an applied electrical field is called the first order electro-optic effect (Pockels effect) and the quadratic effect is called the secondary electro-optic effect (Kerr effect).

*2: $LiNbO_3$
Lithium niobate. $LiNbO_3$ has the highest electro-optic coefficient of the practical materials and is widely used in optical modulators for telecom applications.

*3: Liquid Phase Epitaxy
Liquid phase epitaxy is a crystal film growth technology where substrates are soaked in a solution to prepare specific crystal films on the substrate surface. This technology is capable of growing high quality crystal film with a high growth rate.

*4: Dry etching.
Dry etching is a lithographic technique using highly reactive species such as ions and radicals formed in plasma (discharge). This technique is widely used for the lithography of crystals and glasses.

*5: dB/cm
dB/cm is a unit that indicates the transmission loss of an optical waveguide. 0.5 dB/cm indicates a 0.5 dB loss (about 90% transparency) at a unit length of 1 cm.

*6: Mach-Zehnder interferometer.
Interference is a phenomenon whereby two optical waves overlap thus intensifying or diminishing their amplitudes. A Mach-Zehnder interferometer is a device in which one optical wave is first split into two waves and then synthesized into one wave again to induce optical interference. Mach-Zehnder interferometers are widely used for such telecom applications as optical switches and optical modulators.

*7: Polarization independent operation
Light is composed of two orthogonal vibrations that are perpendicular to the propagation direction. In general, the optical properties parallel and perpendicular to a waveguide substrate are slightly different. The optical performance thus changes depending on the polarization. In particular, electro-optic crystals have a large optical birefringence that depends on the optical axis. Therefore, these polarization dependent properties are serious problems that must be overcome.

- (Fig.1) KTN Crystal
- (Fig.2) Synthesized KTN Crystal
- (Fig.3) Electro-Optic Effects
- (Fig.4) Waveguide Fabrication
- (Fig.5) KTN Optical Switch
- (Fig.6) Results

For further information, contact:
Minako Sawaki, Hirofumi Motai
Planning Division
NTT Science and Core Technology Laboratory Group
Tel: 046-240-5152
E-mail: st-josen@tamail.rdc.ntt.co.jp