Research and Development of Organic Electro-optic Polymers Toward Practical Applications

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After completing his doctoral course, he became JST-CREST researcher in 1996. He joined Communications Research Laboratory (currently NICT) in 1999. Engaged in research on new thin film fabrication techniques, single molecule spectroscopy, organic electro-optic polymers. Ph. D. (Engineering).

The electro-optic (EO) effect is a phenomenon by which the refractive index of a material changes when an electrical field is applied to it. The EO effect is used in devices such as optical modulators and optical switches, which convert electrical signals to optical signals and are key devices for optical communications. NICT is conducting research to improve the characteristics of polymers exhibiting the EO effect (EO polymers) and their applications, developing various types of optical modulators and switches as well as terahertz generation and detection. Here, we introduce development of EO polymer materials, research to improve their thermal stability, on device applications, and the excellent characteristics of EO polymers.

Introduction

Recently, with further increases in the transmission capacity of communications networks, increasing speed of data processing, and diversification of applications, both increasing the bandwidth and decreasing power consumption of optical modulators and switching devices, which are important technical elements of optical communications, have become important issues. EO polymers have a low dielectric constant in the microwave frequency region and the difference between the refractive index for optical waves used in optical communications and the effective refractive index for microwave modulation can be made small, so they are promising for ultra-high-speed operation at 100 GHz or more. Recently, the characteristics of EO chromophores have improved dramatically, as shown below. The EO coefficient, r_{33}, of EO polymers has exceeded 100 pm/V, and they exceed lithium niobate ($LiNbO_3$) in terms of the figure of merit ($FOM = n^3 r_{33}$). As such, EO polymer devices are attracting attention, having both ultra-high-speed response and low power consumption. Ultra-high-speed communication over 100 Gbit/s is also becoming needed for medium and short-distance data communications, in addition to long distance communication networks, and the transition from electrical wiring to optical "wiring" (optical interconnections) has begun. For such applications, reduced size and low cost are important, in addition to high speed and low power consumption. For this reason, hybrid devices combining silicon waveguides with EO polymers are attracting attention.

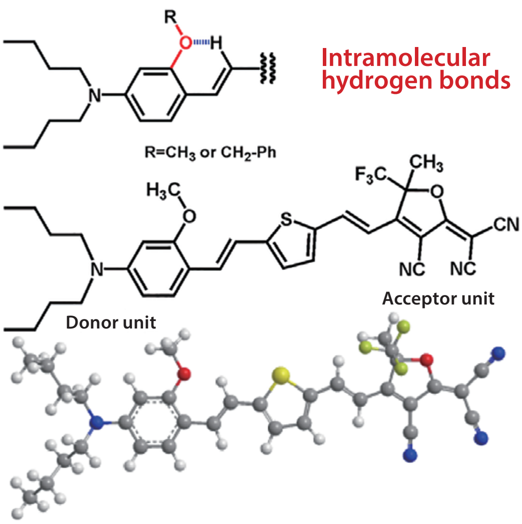


Figure 1 An example of high-performance organic electro-optic (EO) chromophore utilizing intramolecular hydrogen bonds

Design and synthesis of new EO chromophores and a technique to evaluate EO coefficients for EO polymers

EO chromophores are composed of an electron donor unit, an electron acceptor unit, and a π-conjugated unit, and thus EO chromophores have an asymmetric structure. When atoms within the molecule create a double bond, the electrons forming the first bond (σ electrons) bond tightly, while the electrons forming the second bond (π electrons) are more mobile. A π-conjugated system, which is a collection of π electrons, plays an important role in determining the optical and electrical characteristics of a molecule, and it is important to consider the length and orientation of π conjugated systems when designing EO chromophores. We have found that EO performance can be improved by introducing an alkyloxy group at a particular position in the electron donor unit (meta-position of aminobenzene), and using intramolecular hydrogen bonds to stabilize the structure of the π-conjugated system. This has provided new molecular design guidelines for further increasing performance of EO chromophores (Figure 1), and we have successfully developed one of the best EO chromophores in this field. In the EO polymers we developed, this type of EO chromophore is introduced as a side chain on the polymer main-chain. The EO effect is generated in the EO polymer by a process called polling. We also developed a new, highly-reliable method for evaluating the EO coefficient, r_{33}, called the transmission ellipsometric method without an aperture, which we are using for feedback into EO polymer material design (Figure 2).

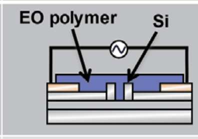
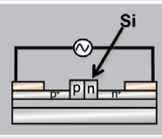
Material/Device	EO polymer/ Si waveguide	Si
Structure		
Bandwidth(GHz)	> 300	37 ~ 70
VπL*Loss (dBV)	2	10
Operation Voltage(V)	< 1	1.1
Power Consumption (mW/GHz)	0.03	3 ~ 6

Figure 3 Comparison of performance of silicon-waveguide/EO-polymer hybrid modulator and silicon-only modulator

■Development of new EO polymers with better thermal stability

EO polymers are applicable in ultra-high-speed modulation at 100 GHz or more, and can be operated with lower power consumption than existing materials, but the thermal stability has been an issue preventing practical application so far, due mostly to orientation relaxation of EO chromophores. At NICT, we have developed EO polymers with a glass transition temperature above 160℃, and found that they show good thermal stability in an environmental-stress test maintaining a temperature of 85℃, as required for optical communications devices.

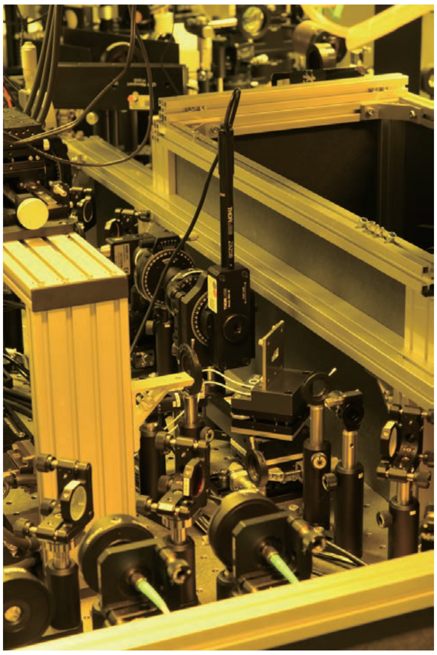


Figure 2 Measurement system for the electro-optic constant, r_{33} (transmission ellipsometric method without an aperture)

■Development of silicon-waveguide/ EO-polymer hybrid devices

As shown in Figure 3, silicon-waveguide/EO-polymer hybrid modulators have promising characteristics including small size (approx. 1 mm), ultra-high-speed (100 GHz or greater), and low power consumption (0.1 mW/GHz or less). This is achieved by combining a silicon waveguide, which has excellent light confinement effect due to the high refractive index of silicon, with the strong EO effect and ultra-high-speed operation of the EO polymer. In contrast, the operating principle of silicon modulators is the free-carrier plasma effect (change in free-carrier density) rather than the pure EO effect, and there are limits to reduction of power consumption and increase of operation speed because of the current flow. Since they are not using the pure EO effect for optical modulation, there is a correlation between phase and amplitude when performing optical modulation, and this may cause difficulty in practical applications.

To apply optical communications for medium and short distance data communications (optical interconnections), NICT is developing silicon waveguide/EO polymer hybrid devices using organic EO materials with high performance and thermal stability, yielding ultra-high speed, low power consumption and size reduction.

■Future prospects

We are developing EO polymer optical modulators and switches and silicon waveguide/EO polymer hybrid devices based on our technologies for developing EO pigments and EO polymer materials, and we are deploying them in society in collaboration with industry. Beyond applications in long, medium, and short-range communications as described above, EO polymers in combination with light sources can be applied to generate ultra-high-speed pulses with low power consumption for sensor applications. The EO polymers we have developed are also very promising for terahertz generation and detection, and we expect they will be developed in a variety of applications.