# Fabrication and Demonstration of a Surface-Normal Metasurface Modulator with Electro-Optic Polymer

## 電気光学ポリマーを用いた垂直入射型メタ表面変調器の試作と実証

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The active metasurface modulators that can be tuned electrically have attracted a great attention for various applications, such as high-density optical interconnect, free-space optical communication, and high-speed imaging [1-3]. In 2017, we have proposed a novel metasurface modulator operating at near-infrared wavelength [4]. By utilizing the bimodal plasmonic resonance and electro-optic (EO) polymer for modulation, we have numerically demonstrated efficient and high-speed modulation capability. Here, we fabricate a proof-of-concept device and experimentally demonstrate 5-MHz EO modulation at 1630 nm wavelength.

Fig.1 shows the schematic view of the modulator, where an EO polymer layer with a thickness $d$ is sandwiched between the bottom (200 nm) and top Au grating layers (100 nm). The grating period $\Lambda$ is designed to be shorter than the wavelength of light to avoid diffraction. When a TM (electric field along $x$ direction) plane wave is normally incident to the device, the metal-insulator-metal (MIM) mode is excited and propagates in the $x$ direction inside the EO polymer layer. When this mode satisfies the resonance condition, the light is confined inside the polymer layer and is eventually absorbed by the metal. By applying a poling voltage between these two Au layers, the refractive index of EO polymer can be modulated via the Pockels effect. As a result, the resonant wavelength can be shifted upon modulation, so that the intensity of the reflected light is modulated at the vicinity of the resonant wavelength [4, 5].

The device shown in Fig. 1 was fabricated for proof-of-concept demonstration. First, the Au and EO polymer layers were deposited on a Si substrate by RF sputtering and spin-coating processes, respectively. After poling the EO polymer, the EB lithography process was used to define the grating pattern. Finally, the top Au and EO polymer layers were etched by ICP-RIE process. Fig.2 shows the SEM images of the fabricated device. The period $\Lambda$, EO polymer thickness $d$ and the grating width $a$ were measured to be 960 nm, 540 nm and 610 nm, respectively.

Fig. 3(a) shows the reflectance spectrum of the fabricated device. We can observe a clear resonant dip at 1610 nm, which matches well with the simulation result. Fig. 3(b) shows the detected optical signal at 1630 nm when a 5-MHz 20 $V_{pp}$ sinusoidal electrical signal is applied between the Au layers. The EO modulation depth of 0.8% is confirmed, from which we estimate the $r_{33}$ coefficient of the EO polymer to be 2.4 pm/V. We expect that the efficiency should be improved largely by optimizing the fabrication and poling conditions, so that the demonstrated device may be useful in various applications, such as optical interconnects and high-speed imaging.

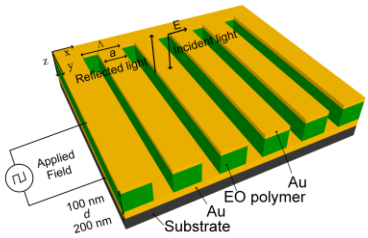


**Fig. 1. Schematic view of the modulator.**

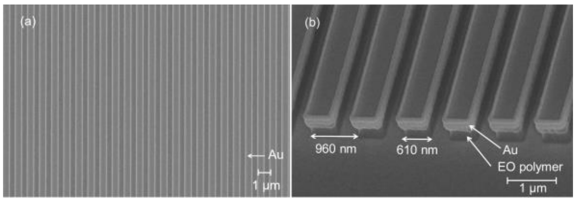


**Fig. 2. Top and birds'-eye SEM images of the device.**

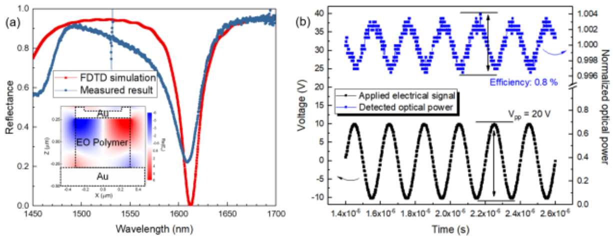


**Fig. 3. Measured and simulated reflectance spectra without modulation (a), and detected optical signal at 1630 nm under 5-MHz modulation (b).**

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