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Analysis of Millimeter-Wave Electro-Optic Modulator Suspended to Gap-Embedded Patch-Antenna on Low-*k* Substrate

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Introduction

Millimeter-wave-photonic technology is attractive to build broadband mobile communication, passive remote sensing, no-inductance electromagnetic compatibility test-ing, so on. This technology enables us to transfer millime-ter-wave (MMW) signals with low loss, low inductance, wide bandwidth and low cost by use of an optical fiber [1]. To utilize this technology, a converter from the MMW to lightwave (LW) signals is important.

We have proposed EO modulators using narrow-gap-embedded patch-antennas [2,3]. The modulation index re-mains low due to small antenna size on only a high-*k* EO crystal as the substrate.

In this report, a new electro-optic (EO) modulator suspended to a narrow-gap-embedded patch-antenna on a low-*k* substrate is proposed for wireless MMW-LW signal conversion. Large antenna size on a substrate with low effective dielectric constant can be obtained. The modula-tion index of the proposed device is larger compared to the devices fabricated on only a high-*k* EO crystal. The analysis of the proposed device for a wireless MMW signal of 60GHz is presented.

Device Structure

The proposed device structure is shown in Fig. 1. A gap-embedded patch-antenna is fabricated on a low-*k* substrate. The antenna length, *L*, and width, *W*, are set a half wave-length and below one wavelength of the designed MMW signal to avoid unwanted higher-order mode effects, res-pectively. The narrow-gap in μm-order is set at the center of the patch-metal, along the *y*-axis. An optical waveguide is fabricated on the reversed side of the EO crystal. The optical waveguide is precisely aligned on the one-side gap edge. The buffer layer is inserted between the patch-metal and EO crystal. A ground electrode is covered on the re-verse side of the low-*k* substrate.

When a wireless MMW signal with *x*-polarization is radiated to a standard patch-antenna with no gap, a stand-ing-wave current parallel to the polarization direction is induced on the patch-metal and becomes maximum at the center. Since the antenna size becomes large using a low-*k* substrate, the received power by the antenna can be im-proved. Then, a narrow-gap is introduced at the center of the patch-metal perpendicular to the surface current, where the gap width is set ~1% of the antenna size. The charac-teristics of the proposed device are almost the same with the standard patch-antenna. By introducing the narrow-gap, the displacement current and strong electric field are induced across the gap due to current flow continuity [2]. The induced electric field can be used for EO modulation. When a LW is propagating in the optical waveguide align-ed on the one-side gap edge, the modulated LW by the wireless MMW signal can be obtained.

Analysis

The proposed device was analyzed numerically using electromagnetic analysis software, HFSS. The designed parameters of the proposed device at a 60GHz operational frequency were set as follow: low-*k* substrate (ε_{rL}=3.5, h_L=130μm), EO crystal (*z*-cut $LiTaO_3$, ε_{rEO}=42, h_{EO}=80 μm), gap-embedded patch-antenna (LxW=800x800μm, G=10μm, t=6μm), and buffer layer (ε_{rB}=4, h_B=0.2μm). The distribution of the calculated MMW electric field in *xz*-plane is shown in Fig. 2. We can see that the strong MMW electric field across the gap is induced.

Modulation index of the proposed device was also analyzed using following equation

$$\Delta\phi(f_m) = \frac{\pi r_{33} n_e^3}{\lambda}\,\Gamma \int_0^W E_m \sin\!\left(n_g \frac{2\pi f_m}{c} y\right) dy\,, \quad (1)$$

where λ and n_g are the wavelength and the group index of LW propagating in the waveguide, respectively, r_{33} is the EO coefficient, n_e is the extraordinary refractive index of the substrate, Γ is the overlapping factor between the in-duced MMW and LW electric fields, and c is the speed of light in vacuum. The modulation index is proportional to the MMW electric field across the gap. The calculated mo-dulation index of the proposed device is shown in Fig. 3.

Conclusion

We propose a new EO modulator suspended to a gap-embedded patch-antenna on a low-*k* substrate for wireless MMW-LW signal conversion. Based on the analysis results, improved modulation index using the proposed device compared to the devices using only a high-*k* EO crystal can be obtained. The modulation index can be improved furthermore using an array structure [3].

References

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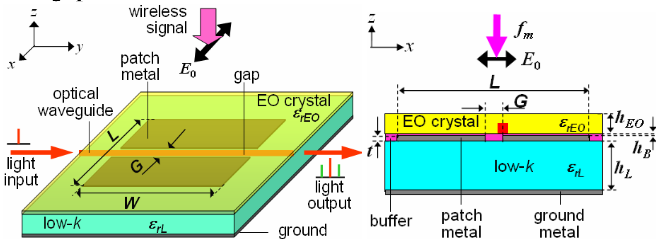

Fig. 1 Device structure: whole and cross-sectional view.

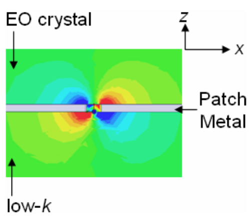

Fig. 2 MMW electric field.

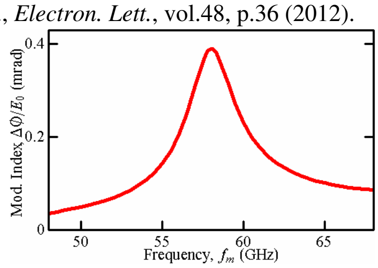

Fig. 3 Calculated modulation index