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Millimeter-wave-Lightwave Converters Using *X*-Cut Ti:LiNbO$_3$ Waveguide Suspended to Patch Antennas Embedded with a Gap on Low-*k* Dielectric Substrate

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Introduction

The demand for high quality multimedia services by mobile devices increases continuously [1]. To meet the demand, large capacity of wireless communication is required. The capacity can be enhanced using millimeter-wave (MMW) carriers with large bandwidth. However, one drawback of the MMW carrier is high transmission losses in the free space. It can be used to realize short range and indoor wireless communication. The small coverage area can be expanded by adopting radio-over-fiber (ROF) technology. The key device in the ROF technology is MMW to lightwave (LW) converters.

Previously, we have proposed MMW-LW converters using *z*-cut LiTaO$_3$ waveguide suspended to patch antennas embedded a gap on low-*k* dielectric substrate [2]. The devices were successfully operated in the 60GHz bands. However, the conversion efficiency remains low due to large effective dielectric constant and buffer layer utilization.

In this report, we propose an MMW-LW converter using an *x*-cut Ti:LiNbO$_3$ waveguide suspended to a gap-embedded patch antenna on a low-*k* substrate. Conversion efficiency of the proposed device is enhanced about 3dB compared to *z*-cut LiTaO$_3$-based device.

Device Structure

The proposed device structure is shown in Fig. 1. The antenna length, *L*, is set a half wavelength of the MMW and the width, *W*, is set below one wavelength of the MMW to avoid unwanted higher order mode effects. 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 reverse side of an *x*-cut LiNbO$_3$ crystal and precisely aligned on the one-side gap edge. A buffer layer is inserted between the patch metal and crystal. The reverse side of the low-*k* substrate is covered by ground.

The low effective dielectric constant value can be obtained using the device with the suspended structure. Furthermore, the proposed device has lower effective dielectric constant compared with the *z*-cut LiTaO$_3$-based device. As a result, large conversion efficiency can be obtained since the antenna size and interaction length become large.

Experiment

The proposed device was designed for MMW operation (f_m=58GHz), with following parameters: low-*k* dielectric substrate (ε_{rL}=3.5, h_L=130µm), EO crystal (*x*-cut LiNbO$_3$, h_{EO}=80µm), and gap-embedded metal patch (LxW=0.8x 0.8mm, G=5µm). The analysis of the device was done using electromagnetic analysis software.

The designed device was fabricated successfully. An optical waveguide was fabricated using the titanium diffusion method on a 500µm-thick *x*-cut LiNbO$_3$ crystal. Gap-embedded metal patch was fabricated using aluminum metal on the crystal, where the gap was located on the optical waveguide. A ground metal was set on the bottom surface of a low-k dielectric substrate. An optical adhesive was layered on the top surface of the substrate. The crystal was flipped over and bonded to the substrate by the adhesive. Finally, the LiNbO$_3$ crystal was polished using diamond slurry to the designed crystal thickness.

The fabricated device was measured experimentally by irradiating MMW to the device and coupling LW to the optical waveguide. The light output was measured by an optical spectrum analyzer. The measured conversion efficiency as a function of wireless irradiation angle is shown in Fig. 2. We can see that the proposed device has 3dB larger efficiency compared with the *z*-cut LiTaO$_3$-based device.

Conclusion

The MMW-LW converter using an *x*-cut Ti:LiNbO$_3$ waveguide suspended to gap-embedded patch antennas on a low-*k* dielectric substrate was proposed. Conversion efficiency enhancement of 3dB was obtained experimentally compared with the *z*-cut LiTaO$_3$-based devices. It can be used for other potential applications include no-induction electromagnetic field measurement, high resolution radar, etc.

References:
[1] Z. Pi et al., *IEEE Comm. Magazine*, pp. 101–107, June 2011.
[2] Y. N. Wijayanto et al., *IEICE JSTQE* (in press).

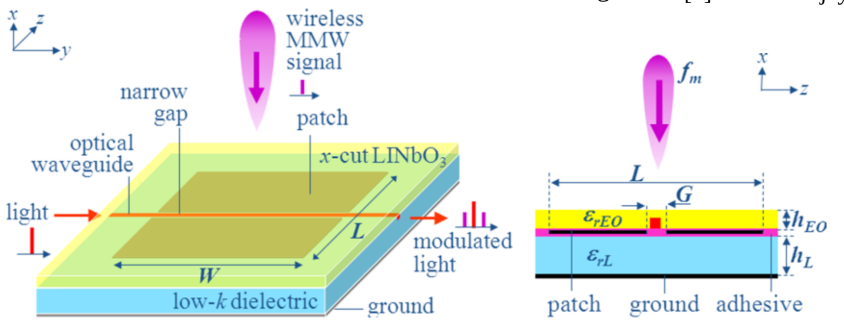

Fig. 1 Device structure: whole and cross-sectional view.

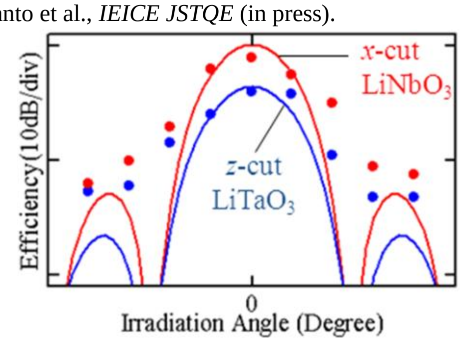

Fig. 2 Measured conversion efficiency.