3D-printed low-loss functional hollow waveguide devices for 200-400 GHz band

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The use of electromagnetic waves in the sub-THz band (0.1–1 THz) is becoming increasingly important for future wireless communications, sensors, radio astronomy, and other applications. Research on elemental technologies and system demonstrations in the sub-THz band is advancing rapidly, contributing to the development of Beyond 5G and 6G technologies. To address the challenges of high-frequency signal transmission through cables, smaller cross-sectional metallic waveguides are employed to propagate wireless signals. As the frequency increases, the cross-sectional size of the waveguide decreases; for instance, the standardized size for the 300 GHz band is WR-3 (a cross-section of waveguides: 0.86 × 0.43 mm^2). These structures are regarded known as sub-mm scale hollow structures with high aspect ratios (smsHS) in bulk metal, are increasingly difficult to fabricate using conventional machining.

3D printers facilitate the creation of hollow structures, including those with high aspect ratios, through their layering process. Despite numerous studies on 3D printing, fabricating smsHS structures for sub-THz waveguide devices remains a significant challenge. To address this, we developed a novel UV-curable resin type 3D printer, RECILS[1], which achieves palm-sized fabrication with the desired resolution of 20–30 µm. However, the objects fabricated with RECILS hinder the confinement of electromagnetic waves. A promising solution is to coat the surface of RECILS-printed objects with metal, thus enabling wave confinement.

This talk presents a novel fabrication technique for waveguide devices in the 200–400 GHz range. Our method integrates smsHS fabrication using RECILS with metal plating on the surfaces of hollow structures and flanges, a process we refer to as RECILS WG Fabrication Technology (RECILS WGFT) [2].

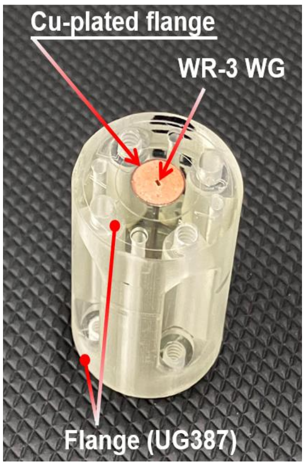

Fig. 1 RECILS-printed straight waveguide for 200–400 GHz

Figure 1 depicts a waveguide with standardized UG387 flanges fabricated by RECILS WGFT. This straight waveguide has a cross-section of 0.86 × 0.43 mm^2 and measures 25.4 mm in length. Its hollow structure and flanges are coated with nickel (Ni) and copper (Cu). The measured insertion losses for these straight waveguides range from 0.5 to 0.8 dB per inch in the 200–400 GHz frequency band, comparable to those of bulk metal waveguides.

Bandpass filter (BPF) waveguide devices, fabricated using RECILS WGFT, incorporate five internal resonators interconnected by a cavity iris, as shown in Fig. 2(a), which presents an X-ray CT image. Fig. 2(b) displays the performance characteristics of three BPFs with resonator lengths L of 410, 440, and 490 µm. The insertion loss in the passband and the extinction ratio were approximately 1 dB and over 30 dB, respectively.

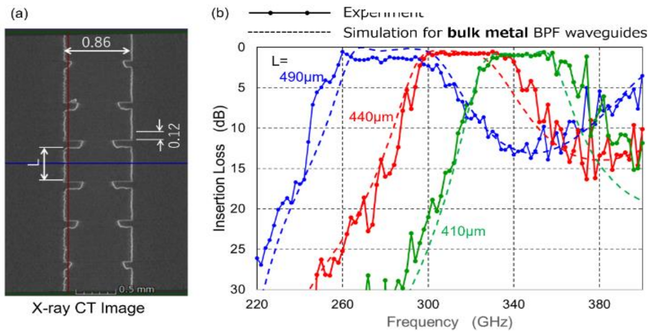

Fig. 2 (a) X-ray CT image of BPF waveguide. (b) Insertion loss of 3 BPF waveguides with L of 490 µm (blue), 440 µm (green), and 410 µm (green). Broken lines represent simulations assuming bulk metal BPF waveguides having the same structures.

Waveguide devices in the sub-THz band fabricated with RECILS WGFT demonstrate low-loss and lightweight properties, showing significant promise in this domain. The ability to produce twisted, bent or spiral waveguides further underscores the potential of this technology. Continued advancements are expected to usher in a new era of 3D integrated waveguide circuits in the sub-THz band.

[1] Kentaro Soeda, Hirosuke Suzuki, Shuichi Yokobori, Kuniaki Konishi, Hiroharu Tamaru, Norikatsu Mio, Makoto Kuwata-Gonokami and Junji Yumoto, Lasers in Manufacturing Conference 2021 Proceedings, https://wlt.de/sites/default/files/2021-10/system_technology_process_ control/Contribution_322.pdf, (2021).
[2] Kentaro Soeda, Kazunori Naganuma, Yoshinori Yamaguchi, Kuniaki Konishi, Hiroharu Tamaru, Norikatsu Mio, Hiroshi Itoh and Junji Yumoto, SPIE Photonics West, Paper 12885-45, January 2024.