Development of W-band waveguide based on plastic additive manufacturing with Ni electroless plating

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Abstract: In general, a millimeter-wave component, such as a waveguide, is made of metal, therefore, it is heavy weight and expensive. In this development, a W-band waveguide based on an additive manufacturing with an electroless plating was demonstrated. We confirmed that the performance of the transmission is approximately −2 dB in 75–110 GHz on a 50 mm long WR-10 waveguide.

Keywords: millimeter-wave, waveguide, additive manufacturing, electroless plating

Classification: Antennas and Propagation

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1 Introduction
The usage of millimeter-wave in anti-collision radar and ultra-high-speed telecommunications has led to the development of the millimeter-wave industry over recent years. The millimeter-wave circuit is heavy because its components, such as waveguides, are made of metal. Furthermore, since the metal parts are manufactured by precision milling, the manufacturing cost tends to being higher. The use of millimeter-wave technology requires lightweight and inexpensive millimeter-wave components. In order to solve these issues, an additive manufacturing (AM) technology is suitable method. In particular, AM is a more inexpensive method than milling or die casting. Several researches have been previously conducted on manufacturing millimeter-wave components by the metal AM and stereolithography [1, 2, 3]. However, the metal AM is not lightweight, and stereolithography has a problem of mechanical strength [4, 5].

In this development, we demonstrated a WR-10 waveguide in the length of 50 mm based on an AM technology using polyamide 11 and Ni electroless plating.

2 AM based waveguide fabrication
The plated AM based waveguide and metal waveguide are shown in Fig. 1. The AM based waveguide is compliant with the WR-10 standard with the UG-387/U flange, and the length is 50 mm. The cross section is 2.54 mm \( \times \) 1.27 mm. In the built parts with polyamide 11, we employed a RaFaEl 300F (Aspect, Japan), which has an ability to form a 100-\( \mu \)m-thickness-layer with a 10 W fiber laser (\( \lambda = 1064 \) nm) output. A Ni electroless plating process on the waveguide surface involves the following two steps. First, repeat a sensitizer process for 1 minute at 30 °C and an activator process for 1 minute at 30 °C twice. Next, a Ni electroless plating process for 100 minutes at 70 °C.

![Fig. 1. Photograph of AM based waveguide and metal waveguide.](image-url)
3 Experimental setup and result

S-parameters were evaluated using a vector network analyzer (Keysight N5247A) with a waveguide extender (OML V10VBA2-T/R-A). The measurement frequency range was 75–110 GHz. Figure 2 (a) shows transmission losses (S21). The transmission loss in the current trial is improved by more than 5 dB comparison with the previous trial.

**Fig. 2.** (a) is comparison of measured transmission losses of metal, current, and previous trial. (b) is comparison of measured reflection of metal, current, and previous trial.
previous trial [6]. The difference between the current trial and the metal waveguide is approximately 2 dB. Figure 2 (b) shows reflections (S11). The difference between the maximum reflection of the current trial and the metal waveguide is approximately 13 dB. Figure 3 shows group delays. It is confirmed that group delay of the current trial waveguide has stable phase characteristic.

![Figure 3](image_url)

**Fig. 3.** Comparison of group delay of metal, current, and previous trial.

In the current trial, the plating thickness was increased in the waveguide in order to improve the conductivity. The plating temperature is increased from 45 ℃ to 70 ℃. The difference of the metal and the current trial in the S-parameter characteristics might be caused a defect of Ni electroless plating inside the AM based waveguide. Therefore, it is necessary to observe the inside of the waveguide with a non-destructive inspection, such as an X-ray computed tomography and improve a plating quality.

4 Conclusion

In this development, a 50 mm long WR-10 waveguide was developed based on the AM technology and Ni electroless plating. The transmission loss of approximately −2 dB and the reflection of approximately −17 dB was obtained in the frequency range of 75–110 GHz. It is improved than the previous trial by higher plating temperature of 25 ℃. The group delay of the AM based waveguide is comparable with a metal waveguide. The performance difference might be caused that the non-plated area is existing inside the AM based waveguide. In the future, we will improve the plating quality and analyze the inside plating layer using a non-destructive inspection instrument.