The fabrication of film-type frequency selective surface (FSS) attachable to Window glass using Ink-jet printing technique

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Abstract

In this paper the fabrication of film-type frequency selective surface using ink-jet printing technique is introduced. This FSS was fabricated on a thin PI film that has a thickness of 75 μm. Flexible polyimide (PI) film was used as the substrate which has hydrophobic surface and commercial silver ink was used as a conductive ink. Sintering process for printed pattern was optimized at 200℃. It was measured that the fabricated FSS has about 10% (6 × 106 S/m) of the conductivity of bulk silver and its S21 is under -30 dB at 95 GHz.

1. Introduction

In recent years, ink-jet printing is inevitable process for fabrication of variable electronic components. Conventional photolithography technique has been widely adopted in the printed circuit board (PCB) industry for manufacturing many circuits. However, this method is time consuming, expensive and very complicated processes because many processing steps are required for fabricate circuits [1-3]. Moreover, conventional photolithographic process produces large quantities of chemical wastes. The ink-jet printing technology has very various advantages, low cost and cleanable process other than the conventional method. Therefore, ink-jet printing technique is considered as the promising alternative of conventional lithographic technology.

The frequency selective surface (FSS) has arbitrary patterns and shows the band pass or stop properties in selected frequency. The FSS has long been a research topic since it has various uses in terms of guaranteeing the fundamental security of frequency resource. For example, the reuse of the frequency spectrum can be improved by using band stop FSS and creating small isolated zones. However, if the FSS is patterned directly onto conventional window glass, the cost would be wasted by a large quantity. Moreover, if someone wants to remove the FSS attached to the glass, he must experience the complicated process. Therefore, we tried to fabricate the film-type FSS which can be attachable to conventional window glass by patterning onto flexible substrate and combining it with the glass. The possibility of directly printed onto flexible substrate was also mean possibility of mass product by roll-to-roll printing method. This paper introduces the fabrication, simulation and measurement results of the film-type FSS attachable to Window glass by ink-jet printing technique.

2. Experimental procedure

The FSS designed hexagonal shape and operating band stop properties at 95GHz for military application by commercial electromagnetic simulation tool (CST Microwave Studio 2006B, CST), Fig.1 shows unit cell of designed FSS [4]. In this research the flexible substrate such a polyimide (PI) film was used. PI film requires the hydrophobic treatment which can convert hydrophilic property of the PI film to hydrophobic property. This process is very important because original hydrophilic property of the PI film results in the spread of the ink. This process was carried out for 1 minute in O2 and Ar plasma atmosphere. Major process conditions are 20 sccm of gas injection, 100 mTorr of working pressure, 300 W of working power then PI film hydrophobic process carried out 5 minute in C4F8 plasma atmosphere.

Under the condition of 1000 DPI resolution of an ink-jet printing equipment(UJ 500, Unijet) conductive silver ink (NPS-J, Harima) was sprayed onto the PI film substrate having the hydrophobic property. The ink-jet printing equipment consisted of a drop-on-demand (DOD) piezoelectric ink-jet nozzle (MJ-AT-01, MicroFab) and the diameter of orifice was 30 μm. The samples of hexagonal FSS which have three different sizes of 1000 μm, 1150 μm, 1300 μm were fabricated to observe the variation of the operation frequency by the size. Fabricated PI film was dried for 24 hour in air under the room temperature condition and sintered for 1 hour in box furnace at 200℃ [5].

The performance of FSS was measured by W-band Antenna Measurement System consisting of standard horn antennas,W-band harmonic mixer and spectrum analyzer. The fabricated film-type FSS were attached to Window glass having the size of 27 cm × 27 cm and then these samples were inserted to Cu holder. At a 50 cm distance plane wave was incident on the fabricated FSS. The frequency of the plane wave was swept from 75 GHz to 110 GHz. The microstructure of fabricated FSS pattern was analyzed by OM (GX51, Olympus) and SEM (S-4800, Hitachi), and its electric properties were measured by 4-point probe (CMT-SR1000N, Chang Min Co., LTD.).

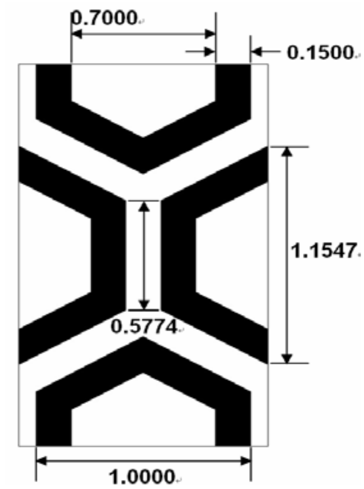

Fig. 1 The unit cell of hexagonal frequency selective surface (FSS)

3. Results and Discussion

Fig. 2 shows the contact angle of substrate (a) before and (b) after hydrophobic treatment. A contact angle was increased from 75.51° to 102.27° according to surface treatment. It means that the condition of spread is improved after hydrophobic treatment. Fig. 3 shows state of printed silver ink at different resolution condition each 600, 800, 1000 DPI, a good shape obtained at 1000 DPI resolution condition. Fig. 4 shows OM and SEM images of printed FSS pattern (a) before and (b) after sintering. Fig. 4(c) shows SEM image after sintering and it shows that the printed pattern was sintered well. Tab. 1 shows the electric properties of printed pattern measured by a 4-point probe. Its conductivity was 6 × 106 S/m and this value is 10% of the conductivity of the bulk silver. Fig. 5 shows the simulated and measured S21 of FSS pattern. Simulated transmission value (S21) of FSS is about -48 dB at 95 GHz and measured S21 value is under -30 dB at 95 GHz. We guess that this difference results from the uneven line like the stairs, as shown in Fig. 4(b). The S21 value of horizontally incident plan wave is similar to that of vertically incident plan wave. This means that the transmission property of hexagonal FSS is independent of the polarization of incident plane wave. On the whole, all characteristics of the measurement results agree with those of the simulation at target frequency.

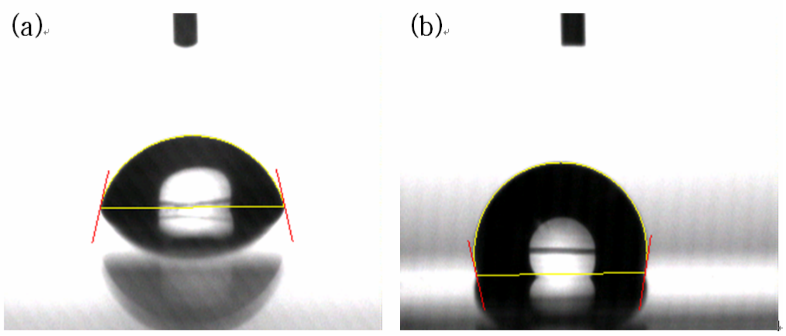

Fig. 2 Contact angle (a) before hydrophobic surface treatment (=75.51˚), (b) after hydrophobic surface treatment (=102.27˚)

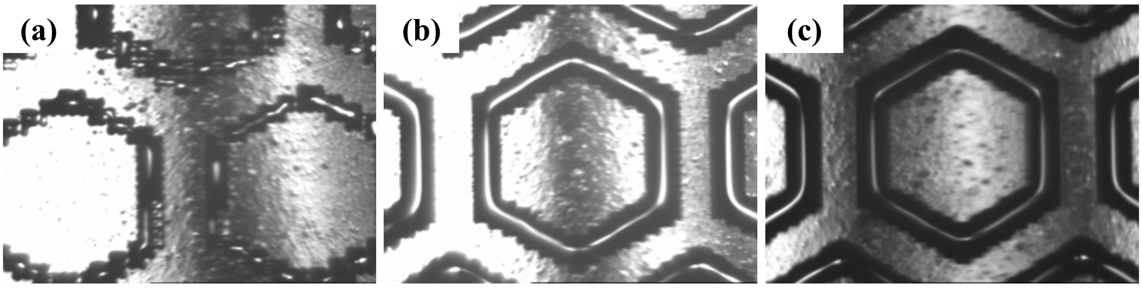

Fig. 3 After hydrophobic surface treatment, printed patterns having different resolutions of (a) 600 DPI, (b) 800 DPI, (c) 1000 DPI

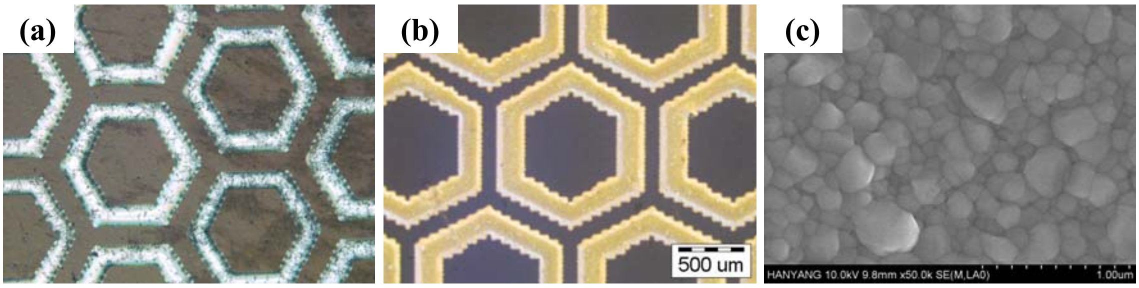

Fig. 4 The optical and electron microscope images; Optical microscope image (a) before sintering, (b) after sintering, (c) scanning electron microscope image of sintering

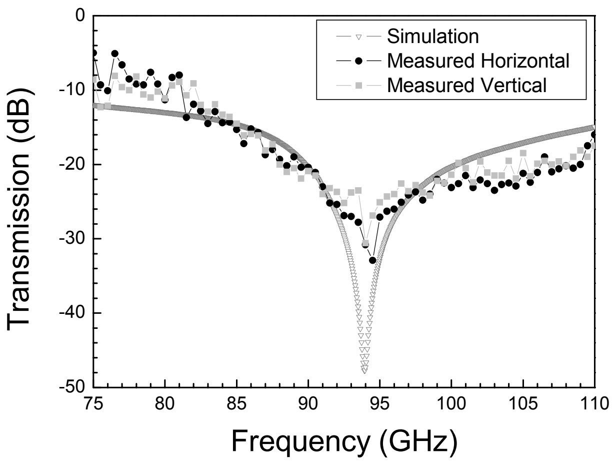

Fig. 5 Simulated and measured transmission property of FSS

Tab. 1 Electric properties of the fabricated FSS pattern

	Sheet resistance (mΩ/□)	Resistivity (μΩ·cm)	Measured conductivity (S/m)	Silver conductivity (S/m)
1000 DPI 200℃ sintered	36	18.0	6×10^6	6×10^7

4. Conclusion

We fabricated the film-type frequency selective surface (FSS) attached to Window glass using ink-jet printing technique. Polyimide (PI) film used as the flexible substrate was processed to have a hydrophobic surface and conductive line of hexagonal FSS was constructed by using a silver ink. Ink-jet printing technique is an attractive alternative to conventional photolithography for direct patterning conductive lines due to low cost, low waste, simple and cleanable process. The fabricated FSS shows band stop ($S21 < -30$ dB) properties at about 95 GHz although conductive lines have 10% (=6 × 106 S/m) of the conductivity of bulk silver. On the whole, measurement results of the fabricated FSS are similar to simulation results. Film type passive components including FSS make use to have various applications because it is very attractive that they can be attachable to the arbitrary material.

5. Acknowledgements

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6. References

1. D. Kim, S. Jeong, S. Lee, B. K. Park, J. Moon, “Organic thin film transistor using silver electrodes by the ink-jet printing technology”, Thin Solid Films, Volume 515, 2007, pp. 7692-7696.

2. B. K. Park, D. Kim, S. Jeong, J. Moon, J. S. Kim, “Direct writing of copper conductive patterns by ink-jet printing”, Thin Solid Films, Volume 515, 2007, pp. 7706-7711.

3. S. M. Bidoki, D. M. Lewis, M. Clark, A. Vakorov, P. A. Millner and D. McGorman, “Ink-jet fabrication of electronic components”, J. Micromech. Microeng., Volume 17, 2007, pp. 967-974.

4. M. Gustafsson, A. Karlsson, “Design of frequency selective windows for improved indoor outdoor communication”, IEEE Trans. on Antennas and Propagation, Volume 54, 2006, pp. 1897-1900.

5. J. W. Park and S. G. Baek, “Thermal behavior of direct-printed lines of silver nanoparticles”, Scripta Materialia, Volume 55, 2006, pp. 1139-1142.