Glass-embedded electromagnetic surface for energy saving future wireless communication

Issued: August 2021
Supercedes: May 2021

B.Kang, H.Choi, C, Kim
Corning Technology Center Korea

Y. Youn, S.Chang, D. Kim, and W. Hong
Pohang University of Science and Technology (POSTECH)

This paper was first presented at SID Display Week 2021.

Abstract

In this paper, the concept of optically transparent glass-embedded frequency selective surface (FSS), functionalities of FSS, application scenarios, design methodology, materials/processes for transparency implementation, and performance verification using both simulation and real samples are described. Value propositions of optically transparent FSS and display integration potentials are also discussed.

I. Introduction

Increasing demands for high data rate, mass connectivity and low latency services require higher wireless channel co-activity than conventional communication systems. This facilitates the introduction of the fifth generation (5G) wireless communication, employing millimeter-wave (mmWave) spectrum. However, mmWave 5G suffers from significant electromagnetic energy degradation through high free-space path loss, penetration loss and diffractions loss, resulting in shadowing regions where wireless channel links are lost. Therefore, it is essential for mmWave communication systems to manage the propagation environment by alleviating the attenuation of tranmitted waves from outdoor to indoor and vice versa [1].

Conventional propagation channel management involves strategic placement of reflector or repeater system between the transmitter and receiver to mitigate the intrinsic penetration, transmission loss and blockage effects [2]. Reflectors redirect incident signals through reflection of electromagnetic waves, enhancing the wireless channel connectivity. However, conventional reflectors require bulky volume and complex fabrication technologies. Repeater systems can establish line-of-sight communication link through amplification of the electromagnetic signals. This active device consist of a receiver unit, band pass filter, power amplifier and transmitter, which collectively increases the total power consumption (energy). In the vantage point of wireless communication and energy efficiency, glass-embedded frequency selective surface (FSS) can be an alternative solution, featuring low-profile, low-cost and energy-saving advantages.

Practicality and feasibility of this energy-saving glass can be improved by adopting optical transparent electrodes as illustrated in Fig. 1. Impedance matching layer can be applicable in outdoor window for alleviating the penetration and transmission losses at certain frequencies. Low-profile and planar reflectarray can substitute the reflector and the repeater, reinforcing indoor wireless propagation channel links without any additional power consumption.

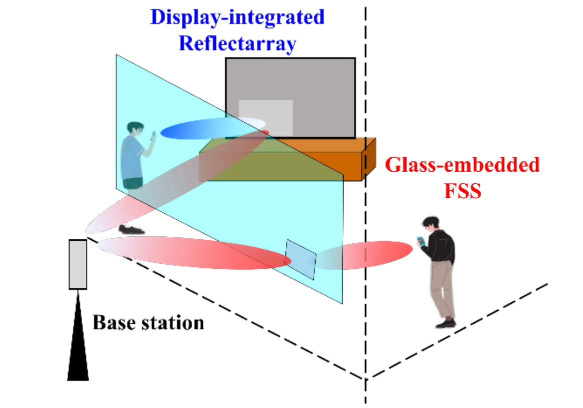

Figure 1. Application scenario of the glass-embedded electromagnetic surface.

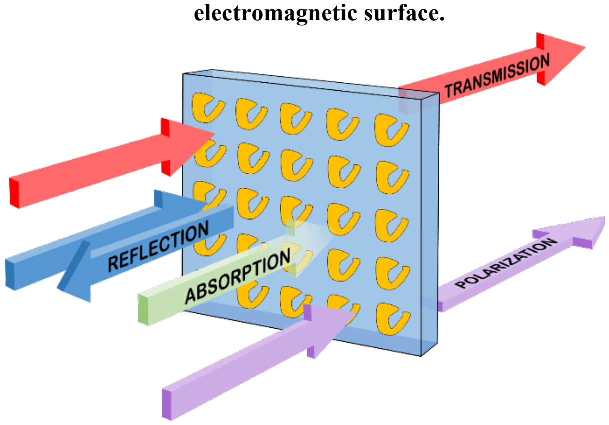

Figure 2. Functionality of the glass-embedded electromagnetic surface (FSS).

II. Proposed Approach

Frequency Selective Surface (FSS), which are electromagnetic filters, consist of periodically-arranged conductive electrodes and dielectric substrates. This electromagnetic surface can transmit, reflect, absorb and convert the waves with frequency and polarization selective responses, as demonstrated in Fig. 2. This filtering behaviors are manipulated by the electromagnetic impedance, which is calculated by the ratio of electrical field and magnetic field. According to the physical configurations of the metal electrodes and the dielectric substrates, electromagnetic coupling and currents are induced, achieving capacitive (low-pass) and inductive (high-pass) filter responses. Therefore, the required FSS behaviors can be formulated by modifying the geometrical parameters of unit cell elements.

Optically transparent FSS

Transparent conductors such as transparent conductive oxide (TCO), polymers, metallic nanowires and thin film metal can be implemented as metal electrodes of the

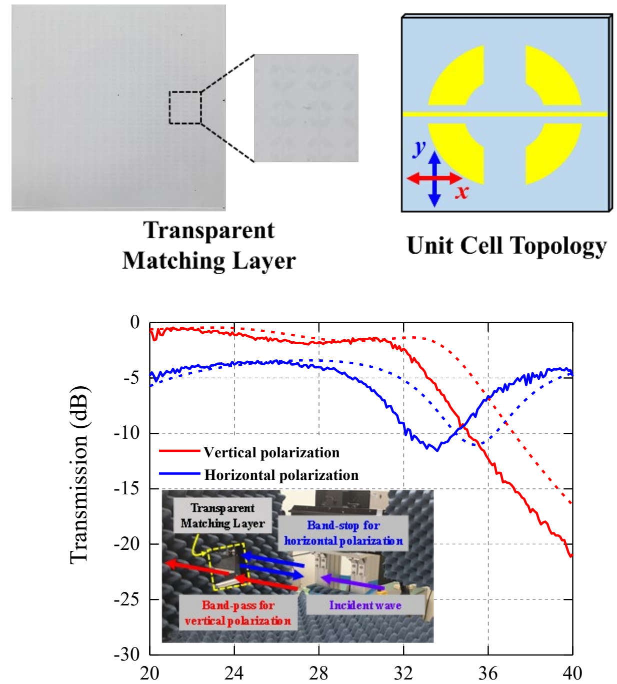

Figure 3. Transparent impedance matching FSS featuring frequency- and polarization- selective responses. (solid: measurement), dotted (simulation).

FSS to achieve sufficient electromagnetic characteristics while exhibiting high optical transparency. Thin film metal features high conductivity, precise fabrication process and high compatibility with glass substrates [3].

Impedance matching layer

Intrinsic impedance difference between free-space and glass impedes the incident electromagnetic wave and attenuates the transmitted signal magnitude. To overcome this impedance mismatching, glass-embedded FSS can be employed as matching layers [4]. These layers mitigate penetration and transmission loss by reducing reflections on the air-glass boundary through frequency- and polarization-selectivity.

Circular ring structure is adopted for low cross-polarization level and low sensibility at the incident angle. Asymmetric split gaps generate different capacitive responses and strip line along x-axis induces additional inductive behaviors for horizontally-polarized wave. This FSS exhibits band-pass transmission for vertical polarization (y-axis) and band-stop for horizontal polarization (x-axis) as demonstrated in Fig. 3. From this simulation and measurement, signal attenuation from penetration loss and transmission of glass substrate is enhanced by this artificial electromagnetic surface.

Reflectarray

Reflectarray formulates a constant phase plane by modifying the reflection phase and magnitude of the scattered fields for focusing and redirecting the reflected wave. This spatial feeding mechanism provides high aperture efficiency and directional beam with low-profile, low-cost and easy fabrication [5].

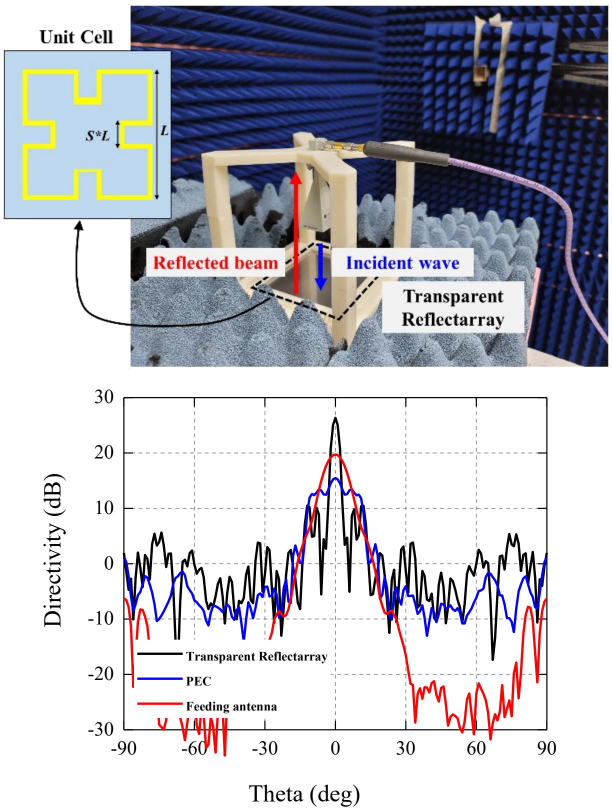

Figure 4. Display-integrated reflectarray configuration and directivity enhancement of reflected beam.

Fractal geometries exhibit reduced mutual coupling and close inter-elements spacing, miniaturizing unit cell period and obtaining high beam resolutions. The unit cell period is miniaturized to 0.3 wavelength of the target frequency at 28.0 GHz. The proposed reflectarray is constructed for formulating the plane phase distributions, resulting in directivity enhancements of 6 dB, as illustrated in Fig.4. From this wireless propagation channel enhancement, energy-efficiency of the communication link is enhanced by a factor of 10 compared to an identical situation using planar metallic sheet.

III. Conclusion

In this article, issues and needs in mmWave 5G communication environment, proposed concept of glass embedded FSS as an alternative solution with low-profile, energy-efficient and possible low-cost potential, design strategy and application scenarios was introduced, and, examples of actual reflectarray pattern design and its directivity improvement capability of 6 dB was demonstrated. The proposed glass embedded FSS with invisible pattern can be applied to existing large display devices, such as TVs and signage displays outdoors, and it also has the potential for integration with mobile devices for energy-efficient mmWave communication with lower signal loss.

IV. Acknowledgements

This research work was conducted as an ongoing collaboration project between Corning Technology Center Korea and POSTECH from 2018.

V. Reference

1. Rappaport T et al. Millimeter wave mobile communications for 5G cellular: It will work!. IEEE access 1; 2013. 335-349 p.
2. Oh J, Thiel M, and Sarabandi K. Wave-propagation management in indoor environments using micro-radio-repeater systems. IEEE Antennas and Propagation Magazine 56.2; 2014. 76-88 p.
3. Lee S et al. Optically transparent nano-patterned antennas: a review and future directions. Applied Sciences 8.6; 2018. 901 p.
4. Yang Z et al. Design of a thin and broadband microwave absorber using double layer frequency selective surface. Journal of Alloys and Compounds 699; 2017. 534-539 p.
5. Costanzo S et al. Fractal reflectarray antennas: state of art and new opportunities. International Journal of Antennas and Propagation; 2016.