

Low Permittivity Environmentally Friendly Lenses for Ku Band

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Abstract—Lenses can be used to focus and disperse the electric field emitted by the antenna. Sustainable and environmentally friendly lenses were made from lithium molybdenum oxide (LMO) glass composite. Half spherical lenses with a diameter of a 30 mm were fabricated from LMO composite, and the antenna properties were measured with a waveguide feed. The lens enhanced radiation pattern was measured at Ku band, and the improvement in the gain was found to be 2 dB.

1. INTRODUCTION

In telecommunications smart antenna systems lenses can be used for main beam focusing, sidelobe suppression, and beam switching purposes [1]. Lenses come with wide variety of shapes and materials, but very low dielectric losses. Ceramics offer good stability at higher temperatures, and their permittivity can be adjusted. Meanwhile, one downside has been high manufacturing temperature resulting in high energy consumption in fabrication which raises the production cost. After the invention of the room temperature fabrication method (RTF), water-based suspension of lithium molybdenum oxide (Li_2MoO_4 , LMO) ceramics can be fabricated at room temperature instead of temperatures over 400°C [2]. It has relative permittivity of 5.1 and loss tangent value of 0.0035 at 9.6 GHz [3, 4]. Also, at 4 GHz an LMO ceramics patch antenna has been demonstrated [5]. Adding a different dielectric material into an LMO mixture its dielectric properties can be changed. $\text{Li}_2\text{MoO}_4\text{-TiO}_2$ composites have relative permittivity 6.7–10.1 and loss tangent value 0.0011–0.0038 depending on its volume percent at 9.6 GHz [6]. $(1-x)\text{Li}_2\text{MoO}_4\text{-}x\text{Mg}_2\text{SiO}_4$ has a permittivity of 5.05–5.3 at 9 GHz (loss tangent not mentioned) [7]. 3D printed LMO has a permittivity of 4.4 and loss tangent value of 0.0006 at 9.6 GHz [8], and ultra-low permittivity LMO composite having permittivity of 1.12 and loss tangent value of 0.002 [9] has been reported. The research of RF applications for LMO composites is in its early stage. In this letter, Lithium molybdenum oxide (Li_2MoO_4 , LMO) hollow glass microspheres (HGMS) composite and lenses with a diameter of 30 mm are made and analyzed at Ku band with a waveguide feed.

2. EXPERIMENTAL

2.1. Material Fabrication and Molding

The lenses were made by mixing the HGMS with the LMO solution. HGMS were purchased from Kevra corporation (Finland). HGMS are an inexpensive solution to reducing the dielectric values of composites as they have permittivity of ~ 1.5 (at 100 MHz). The spheres were C-type glass with 50–75% SiO_2 , an average particle size of 40–80 μm , a volumetric density of 0.1–0.15 g/cm^3 , a bulk density of 0.2 g/cm^3 , and a temperature resistance up to 650°C according to a manufacturer. The LMO (> 99%; Alfa Aesar,

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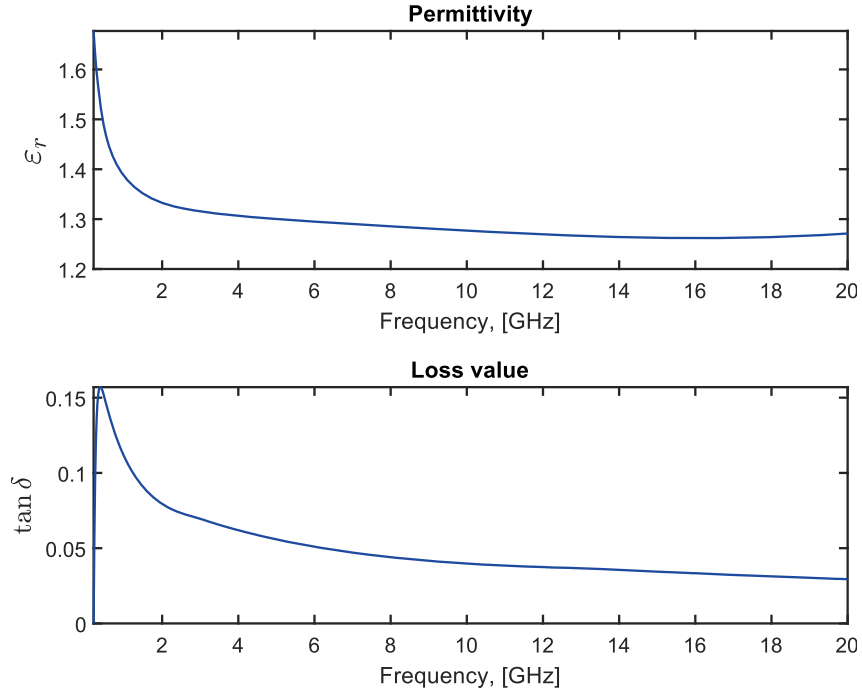


Figure 1. Measured dielectric values of LMO-HGMS composite at 200 MHz–20 GHz.

USA) was dissolved in water to achieve a solution containing 400 g/l LMO. The HGMS-LMO paste was achieved by mixing together 2.5 g HGMS and 10 g LMO solution using a spatula. The resulting composite paste was manually extruded into 30 mm diameter hemispherical-shaped silicone molds. The samples were allowed to dry in the molds at room temperature for 48 hours followed by drying in the oven for 18 hours at 80°C without the molds. From a sustainable point of view, the relatively low processing temperature compared to other ceramics saves resources, and the noted phenomenon of LMO composites water dissolvability is significant. LMO-HGMS composite has a low permittivity of 1.3 and low loss value of 0.002 measured with SPDR (5.2 GHz) resonators. At Ku band, permittivity of 1.26 and loss value of 0.03 are measured with (DAK3.5-TL Probe Beam (200 MHz–20 GHz)) shown in Fig. 1.

Total of five lens samples were fabricated with a molding process and are shown in Fig. 2.

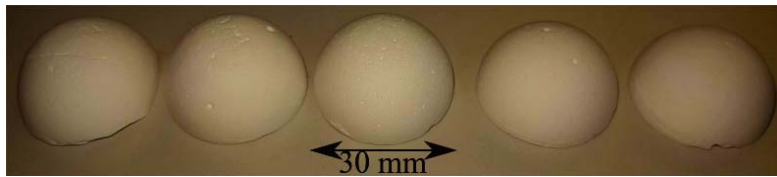


Figure 2. Manufactured half spherical LMO glass composite lenses with the smoothed sample on the right.

3. ANTENNA MEASUREMENT

Manufactured LMO-HGMS lenses were evaluated on the waveguide at 15–18 GHz Ku band round waveguide (lab made). The lens antenna was measured with a SATIMO StarLab antenna measurement system. Fig. 3 shows the SATIMO and CST simulation setup. The output of the round-shaped waveguide is seen at the center, and the lens lies on top of 20 mm (i.e., the focal length of the lens) thick foam moved to the side of the wave guide. The foam had roughly a 13 mm hole, so the lens was

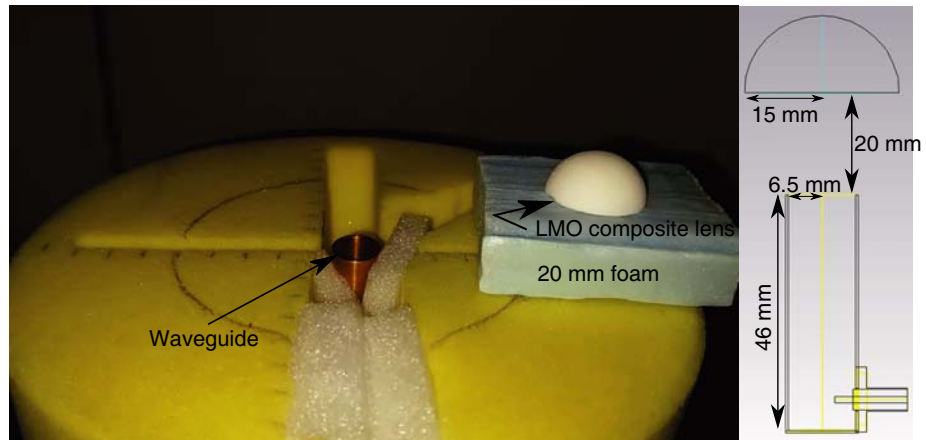


Figure 3. Far field measurement setup of LMO lenses with Ku band round wave guide. Schematic shows the dimensions of the waveguide and CST model.

supported by 1 mm at the edges. As in Fig. 1, the manufactured lenses looked partly rough on the surface except for the one smoothed with sandpaper (Grit 400 (P800) and Grit 600 (P1200)).

Operation principle of the lens + waveguide setup is as follows: Spherical wavefront which exits from the waveguide is converted by the lens to a planewave, shown in Fig. 4. Simulated result shows that the propagated half spherical wave is converted to a plane wave by the lens. Lens also increases the intensity of the plane wave. (CST simulation parameters were as follows: -50 dB precision and hexahedral mesh).

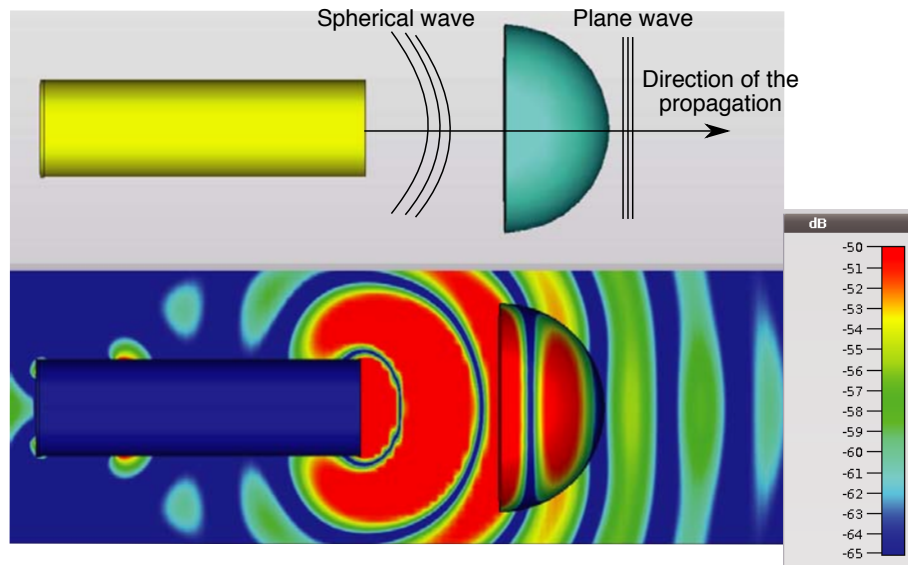


Figure 4. Operation principle of the waveguide lens setup: Lens is expected to turn spherical wave to a plane wave and increase its intensity.

Figure 5 illustrates measured far field patterns of the unsmoothed and smoothed antenna lenses together with simulated results and the effect of the different lens elevations, i.e., the focal lengths of the lens were measured. In Fig. 5(a), the antenna gain was 8 dB in the boresight direction (0 degrees). Smoothing the lens resulted in no notable change in the far field pattern that both the lenses were measured to have equal 10 dB gain at 20 mm distance. On the other hand, changes in the elevation of

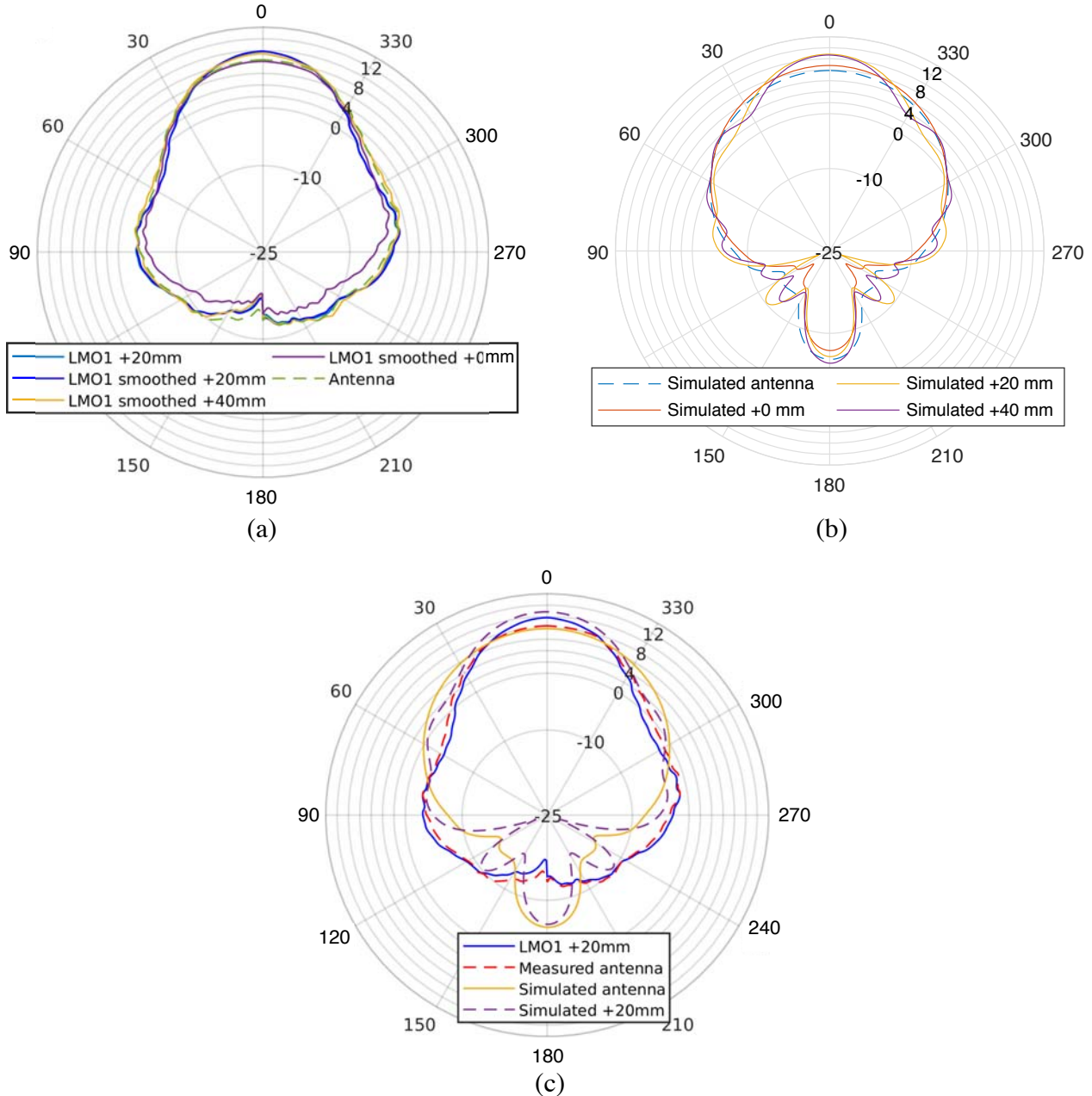


Figure 5. (a) Measurement (E -field, Φ 0 degree) results of the LMO lens smoothing and lens extensions change, (b) simulated results, (c) combination of measurement and simulated results.

the lens and the focus position of the lens resulted in a different total gain. When the lens was put directly on top of the wave guide at zero distance, the gain dropped by -0.5 dB below the antenna gain, and $+20$ mm and $+40$ mm extension lengths (i.e., lens was raised by using the foam) improved the original gain value to 10 dB and 9.5 dB, respectively. The beam patterns shrink a bit by the lens installation that is seen in between 30 and 60-degree angles in Fig. 5(a). Corresponding characteristics is also presented in the simulated results in Fig. 5(b) and combined result in Fig. 5(c).

Figure 6 shows the statistical data of the far field E -field patterns of five LMO lenses. There was no notable difference in the gain maximum (10 dB \pm 0.2 dB), but the biggest difference was observed at the 30-degree angle in the beam (± 4 dB). As the lens dried it also shrank, and the shrinking impact is seen as the difference in the width of the main beam. The change in the shape of the far field pattern

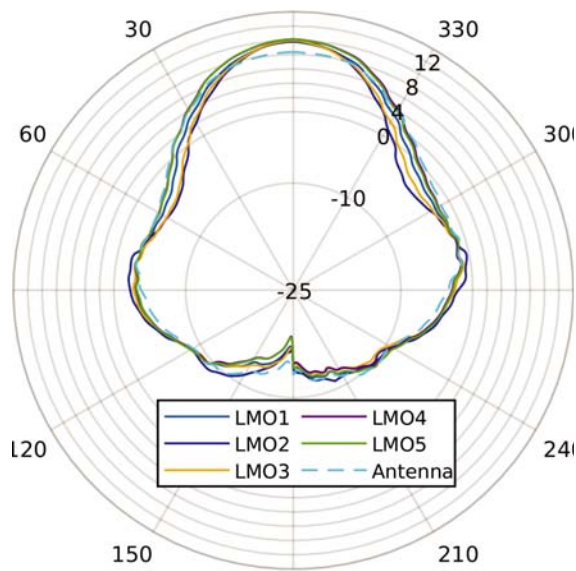


Figure 6. Far field measurement (E -field, Φ 0 degree) results of the multiple LMO lenses.

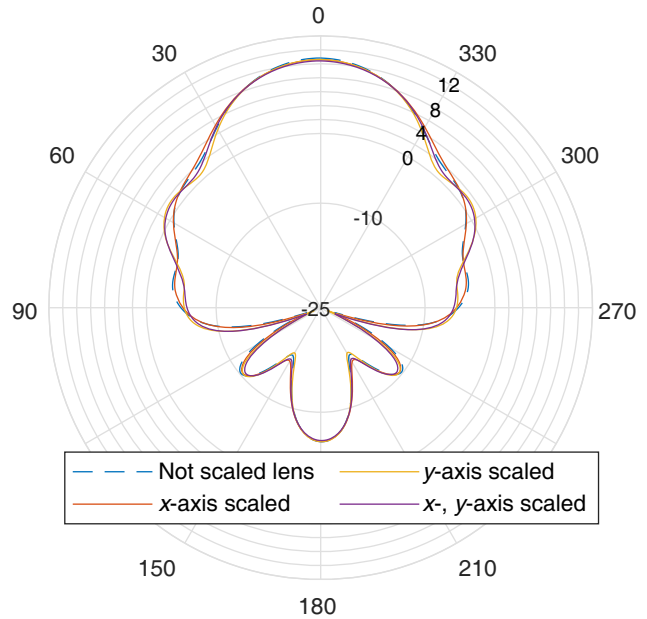


Figure 7. Simulated effect from the lens shrinking to the far field pattern.

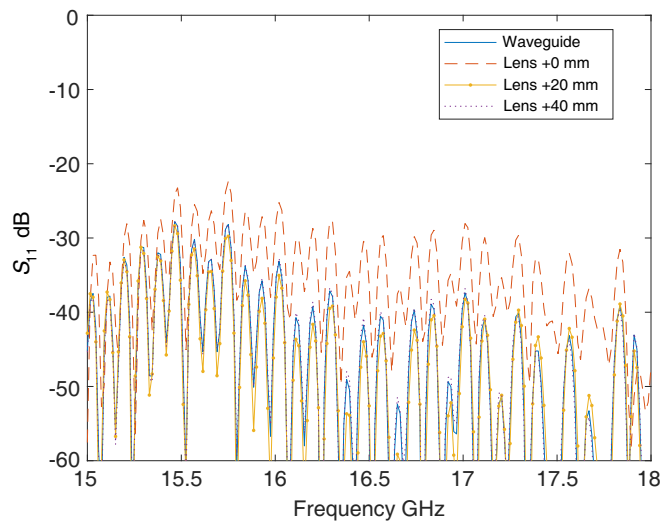


Figure 8. Measured matching parameter.

due to lens shrinkage was simulated, and the results are shown in Fig. 7. The lens was simulated by scaling both of the X -axis and Y -axis by 0.2. As seen from the results, a slight deformation leads to around 2 dB change in the main beam sides. Waveguide matching with two different extension lenses was measured. The waveguide had an average matching of -40 dB, and the lenses with 20 mm and 40 mm extensions had the same matching, shown in Fig. 8.

4. HYBRID MANUFACTURING

LMO composites could be utilized in hybrid manufacturing. The hybrid manufacturing processes are based on the simultaneous and controlled interaction of process mechanism and/or energy sources/tools having a significant effect on the process performance [10]. So, in one processing zone, multiple steps

are performed at the same time which leads to more efficient processes which is more cost effective. Different things have been manufactured with hybrid techniques, e.g., ceramic hemispheres and pyramid substrates using 3D printing, laser drying, and CNC milling at the same manufacturing station [11], 5G Waveguides, and filters using 3D printing and metallic paint [12] and printed patch antennas [13]. LMO has been proven to be 3D printable which could be utilized in 3D printing hybrid manufacturing as well as other ceramics [8, 14]. As the LMO-HGMS study is still at early stages, 3D printability is still under research.

5. CONCLUSION

In conclusion, lithium molybdenum oxide glass composite offers completely new options for low permittivity, very low loss, and high thermal-resistance lens materials. To realize sustainable and environmentally friendly components, only two materials need to be mixed. Lens shaping can be achieved by molding technology, and only a low temperature heat treatment is needed. The LMO composite is a reasonable material for mass production of low permittivity lenses. The fabricated lens had low losses, and although it had relatively small dimensions being only two times larger than the waveguide diameter, it enhanced the gain by 2 dB. Further increase in gain can be reached by increasing the lens diameter or by changing its shape. In the future LMO glass composite lenses will be studied with terahertz antennas.

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