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Combining thermal insulation and mobile communication in buildings: influence of laser-treated glazing on microwave propagation

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Abstract. With the purpose of reducing the heating energy in buildings, it is common practice to install energy-efficient windows to increase the thermal insulation of a façade. These insulating glass units (IGU) include a thin silver coating acting as an infrared mirror which reduces the thermal losses that occur through radiation, but at the same time reflects the microwaves for mobile communication. To address this drawback, a specific laser treatment is performed on the silver coating which strongly improves the transmission of microwaves through the window. In this study, the attenuation of microwaves signal was analyzed inside the SolAce unit in the "NEST" research building at the Swiss Federal Laboratories for Materials Science and Technology (EMPA) in Dübendorf. Two configurations (with and without laser-treated glazing) were carried out by interchanging two hinged windows. The results showed a significant improvement in signal strength in the configuration with laser-treated IGUs. A transmission loss contour plot of the SolAce unit showed a highly directional propagation of the wave which suggests that more than two windows should be treated to achieve better mobile communication in the entire unit. The novel patterned coating is thus especially valuable in the building sector to increase the microwave signal for mobile communication. To the best of our knowledge, this is the first implementation and testing of laser-treated coating for energy-efficient glazing in the building sector.

1. Introduction

The demand for mobile communication between persons and more recently between objects (Internet of Things or IoT) is continuously and rapidly increasing. Simultaneously, modern energy-efficient windows (double and triple glazing) have become a standard in the building sector. The combination of modern insulating glass unit (IGU) and the large use of reinforced concrete leads to bunker-like buildings which are signal-proof to microwave transmission (acting like a Faraday cage). The signal attenuation is due to the low-emissivity (low-e) silver coating found in IGU which improves the thermal insulation but also reduces the microwave transmission by up to 30 dB [1–3]. Several studies have been carried out to effectively measure

the signal loss caused by IGUs in buildings [4–6]. This attenuation reduces the throughput which in turn leads to poor internet and phone call quality inside modern buildings. At the same time, the ever-increasing use of IoT in households and offices leads to higher demand for reliable network throughout the buildings [7]. As the 5G mobile technology is rolling out, IoT will increasingly rely on the 5G network which improves the response time and extends the number of connected devices. The influence of IGU on 5G mmWave bands has already been investigated in different studies, especially for double glazing windows [8–10].
The aim of this study is to show that a specific laser treatment carried out on the selective low-e coating can strongly improve the transmission of microwaves in buildings. The focus is laid upon further investigating the influence of triple glazing and examining the spatial propagation of microwaves inside a room.

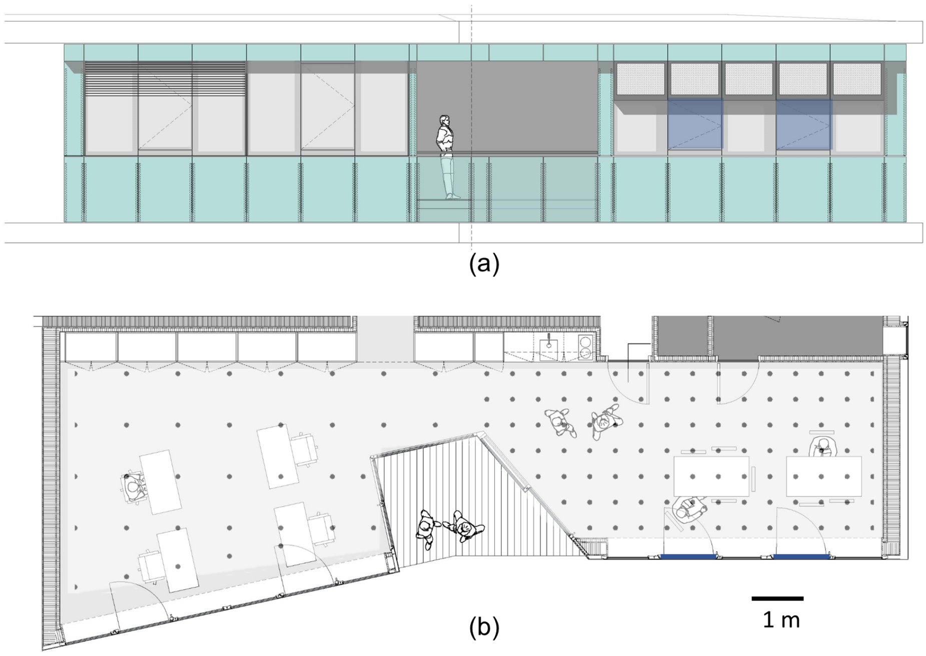

Figure 1: (a) Architectural plan of the south-west façade and (b) Top view of the SolAce unit where each dot represents one measurement. In both Figures, the two windows that were replaced with microwaves transparent windows are shown in blue.

2. Material and Methods

The study was carried out in November 2018 in the SolAce unit which is part of "NEST": a modular research and innovation building at EMPA in Dübendorf [11]. SolAce focuses on two main goals: maximum energy generation on the façade and optimum comfort for residents inside the unit. The energy production is achieved by solar cells and solar thermal collectors with colored glazing which are built into the façade (as shown by the turquoise panels in figure 1a). In order to understand how the electromagnetic (EM) waves for mobile communication are propagating inside a building, a series of two measurements were performed. In the first configuration, standard IGUs with triple glazing and two low-e coatings were used. For the second part, two hinged windows (as shown in blue in figure 1a) were interchanged with laser-treated glazings. The layout of the triple glazing window which has a U-value of 0.5 W/m^2K and g-value of 59 %, can be seen in figure 2a. Figure 2b and 2c show, respectively the laser scribing process used to treat the low-e coating and a microscope image of the resulting coating after ablation. This treatment does not affect the energy performance of the windows, g-value measurements and more information regarding the laser process is provided in previous works [1, 3, 10].

A measurement device based on Nemo Handy software (developed by Keysight) was used to record the reference signal received power (RSRP) for the 4G Long Term Evolution (LTE) network over the entire surface of the unit. The receiver antenna was placed on a tripod at a height of 1.30 m above the ground. The pattern that was followed for the measurement is shown in figure 1b. It consisted of a 0.5 m square grid pattern on the right side of the unit (where the windows were changed) and 1 m grid on the left side where no modification was done between the two configurations. The study was carried out at a frequency of 1.8 GHz using LTE frequency-division duplexing (FDD) band 3 (also known as DCS: Digital Cellular System). The nearest cellular antenna (PCI 131) operated by Swisscom was situated on the top of the nearest building and 140 meters from the façade. Each measurement was done by averaging RSRP values over 30 seconds to reduce the possible fluctuation of the signal. Furthermore, a reference RSRP was taken every 15 minutes outside the unit (0.4 m away from the façade) and was used to calculate the attenuation caused by the walls and windows.

In addition to the measurement done at NEST, a simulation was carried out on Ansys HFSS based on the same parameters presented by Burnier et al. [3]. The HFSS-model was first validated with the simulation of a double glazing unit with low-e coating based on the measurements presented by Bouvard et al. [1].

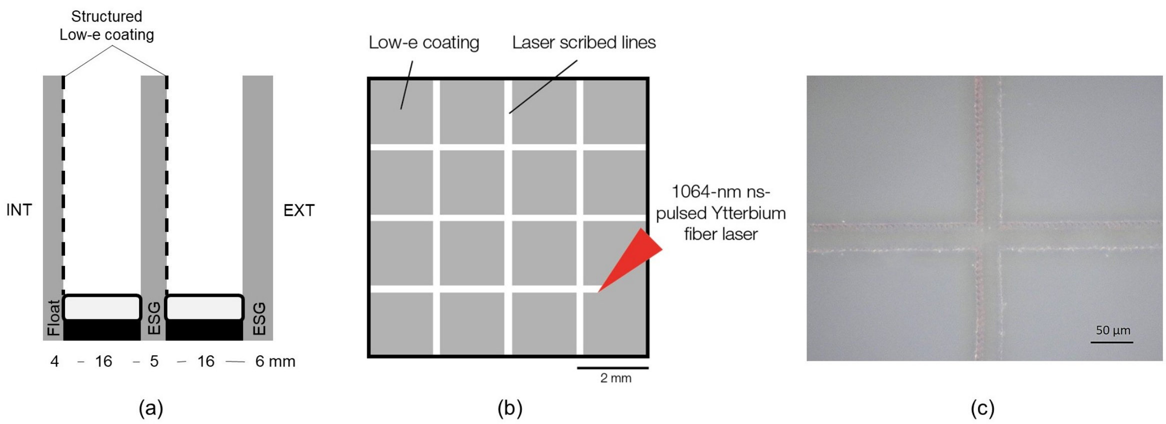

Figure 2: (a) Schematic design of a triple glazing window installed in the SolAce unit. The window consists of one 4 mm standard soda-lime (float) pane combined with two thicker (5 and 6 mm) ESG (tempered glass) panes with two air-gaps of 16 mm. Two structured low emissivity insulating coatings can be found on surfaces 3 and 5 (1 being the outer and 6 the inner surface). (b) Drawing showing the ablation principle of the insulating transparent coating. (c) Microscope image of the low-e coating after the ablation process. The width of each line is approximately 25 μm.

3. Results and Discussion

Figure 3 presents a full-wave 3D electromagnetic (EM) simulation of three different types of triple glazing windows: with two full low-e coatings, with two laser-treated low-e coatings and without any coating. It can be seen that the IGU with two silver coatings shows a significantly higher attenuation compared to the glazing without coating and with laser-treated coatings. At the frequency examined in this study (1.8 GHz) the signal strength was improved by 65 dB for an incoming wave normal to the surface of the glazing. Ängskog et al. [5] measured the signal attenuation of triple glazing in a semi-anechoic chamber and found values between -30 and -60 dB, indicating a slightly lower attenuation than what we have obtained with our simulation. This inconsistency could be due to the fact that our model does not takes into account the framing of the window, it simulates an infinitely large glazing without any edge-effects. The attenuation of the standard IGU with two low-e coatings may thus be overstated. It should also be noted that the behavior of the transmission loss of the EM wave depends on the angle of incidence, which in the case of the SolAce unit is around 30°. A comparable simulation with an incident angle of 30° for s and p polarization was also carried out and showed similar results. In the frequency range above 3 GHz the two IGUs (no coating and laser-treated) show a stronger attenuation which is most likely due to resonance frequencies between the glass cavities creating constructive and destructive interferences [10].

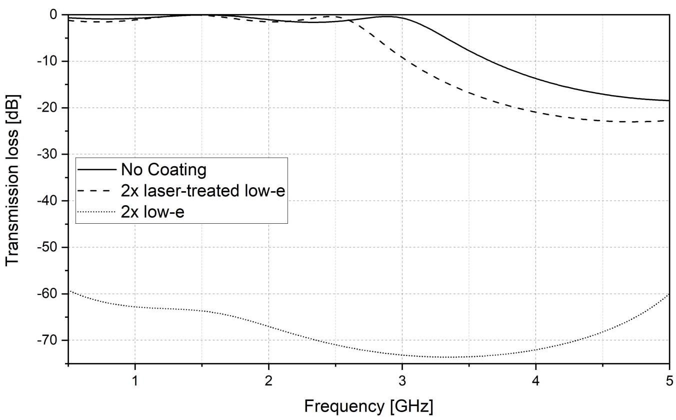

Figure 3: Simulation of EM-waves propagating perpendicularly through a triple glazing unit based on the configuration shown in Figure 1a at frequency ranging from 0.5 to 5 GHz. The behavior of laser-treated window is comparable to an IGU without low-e coating, while the low-e coated glazing strongly attenuates the signal.

A contour plot of the measured values is presented in Figures 4a and 4b. It was smoothed using thin-plate spline (TPS) algorithm with a total points increase factor of 200 and smoothing parameter of 0.0001. On the right part of the unit (where the windows were interchanged) a significant improvement in signal strength between the two configurations can be observed. This increase is especially visible in Figure 4b where the improved signal (in green) follows a straight line with an angle corresponding to the incident angle, i.e. 30°, starting from the opening of the two windows, suggesting a highly directional propagation of the EM waves inside the building. In both configurations, a green spot of higher signal power can be seen in the bottom-middle part. A possible explanation for this might be that the wall on the edge is made of agglomerated wood panel and wood fiber which is relatively transparent to the EM waves.

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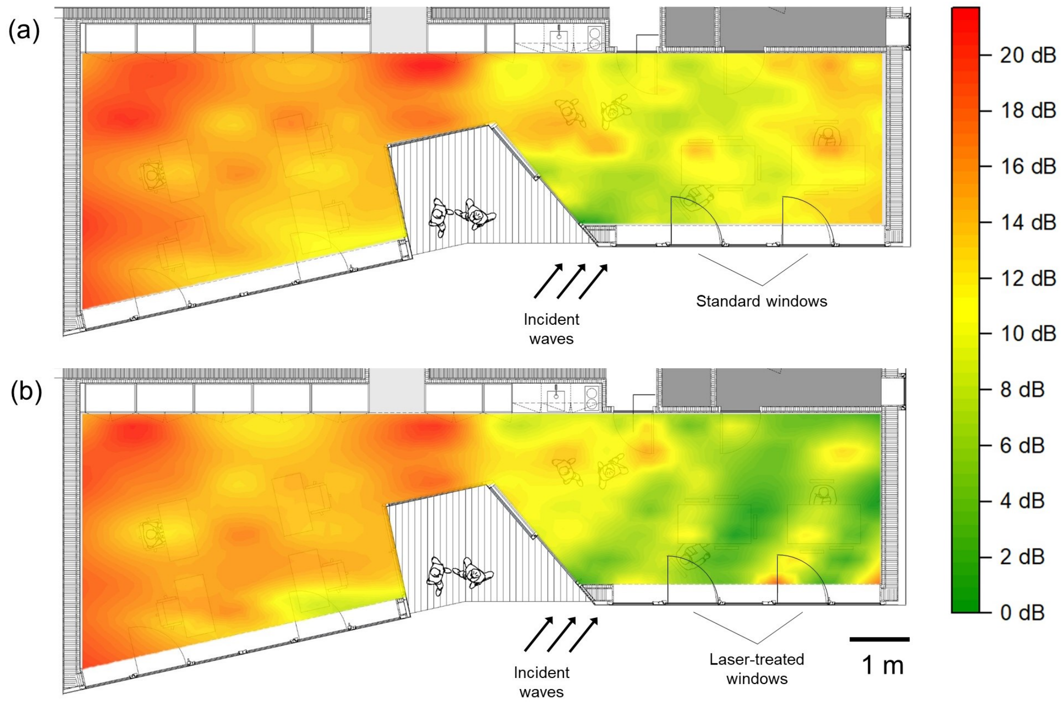

Figure 4: Contour plot presenting the change in RSRP values between the inside and outside of the unit where (a) shows the first configuration with standard IGU (triple glazing with two low-e coatings) and (b) two hinged windows on the bottom right were replaced with laser-treated glazing. This modification resulted in a highly directional increase of the signal strength.

It should be noted that the values shown in Figures 4a and 4b are the relative difference in RSRP between the inside and outside of the unit. In order to assess the quality of the signal, the absolute RSRP value measured in dBm is more appropriate. RSRP represents a key measure of signal level and quality for modern LTE networks. Values below 80 dBm are described as excellent, between 80 - 90 dBm as good, 90 - 100 dBm as poor and no signal is received above 100 dBm [12]. In the case of the SolAce unit, RSRP of 71 dBm was measured outside the façade and approximately 91 dBm in the top left corner of the room (see red spots in Figures 4a and b). It means that the LTE signal is described as "poor" even-though the emitting cellular antenna is located only 140 m away from the NEST building situated in a high population density near Zürich. The difference in RSRP between inside and outside (20 dB) represents a decrease in signal intensity by 100 times. This transmission loss is lower than the simulated value presented in Figure 3 which may be explained by high transmission through the wooden material used in the outer walls. As a contrast with the left side of the unit, the right part, equipped with laser-treated windows, shows excellent RSRP values around 75 dBm corresponding to an increase of 16 dB between the two configurations. It is thought that this result could be replicated to the entirety of the unit if all the windows were treated with our laser process. The reference signal received quality (RSRQ)and signal to noise ratio (SNR) were not evaluated for each points but a single measurement was taken and gave respectively, -9.2 dB and 7.3 dB which corresponds to excellent signal quality [12].

4. Conclusion

Laser-treated low-e coatings for energy-efficient glazing was implemented in a building and the resulting signal strength for mobile communication was mapped. The data show a significant improvement in signal strength for the configuration with laser-treated windows compared to standard insulating glass units. RSRP values increased by up to 16 dB in the area area behind the newly installed windows. A signal attenuation contour plot of the SolAce unit shows a highly directional propagation of the wave which suggests that more than two windows should be treated to achieve better mobile communication in the entire unit. In conclusion, the novel laser-treated coating is especially valuable in the building sector to increase the quality of wireless networks which will become increasingly important for IoT and 5G mobile technology.

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References

[1] Bouvard O, Lanini M, Burnier L, Witte R, Cuttat B, Salvadè A and Schüler A 2016 *Applied Physics A* **123** 66 ISSN 1432-0630
[2] Bouvard O, Lanini M, Burnier L, Witte R, Cuttat B, Salvadè A and Schüler A 2017 *Energy Procedia* **122** 781–786 ISSN 1876-6102
[3] Burnier L, Lanini M, Bouvard O, Scanferla D, Varathan A, Genoud C, Marguerit A, Cuttat B, Dury N, Witte R, Salvadè A and Schüler A 2017 *IET Microwaves, Antennas & Propagation* **11** 1449–1455 ISSN 1751-8733
[4] Rodriguez I, Nguyen H C, Jorgensen N T K, Sorensen T B and Mogensen P 2014 Radio Propagation into Modern Buildings: Attenuation Measurements in the Range from 800 MHz to 18 GHz *2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall)* pp 1–5
[5] Ängskog P, Bäckström M and Vallhagen B 2015 Measurement of radio signal propagation through window panes and energy saving windows *2015 IEEE International Symposium on Electromagnetic Compatibility (EMC)* pp 74–79
[6] Hoppe R, Wolfle G and Landstorfer F M 1999 Measurement of building penetration loss and propagation models for radio transmission into buildings *Gateway to 21st Century Communications Village. VTC 1999-Fall. IEEE VTS 50th Vehicular Technology Conference (Cat. No.99CH36324)* vol 4 pp 2298–2302 vol.4
[7] Palattella M R, Dohler M, Grieco A, Rizzo G, Torsner J, Engel T and Ladid L 2016 *IEEE Journal on Selected Areas in Communications* **34** 510–527 ISSN 0733-8716
[8] Kim H and Nam S 2021 *IEEE Antennas and Wireless Propagation Letters* **20** 108–112 ISSN 1548-5757
[9] Fleury J, Burnier L, Lanini M, Domenico M D, Zimmermann E, Genoud C, Salvadé A and Schueler A 2019 *Journal of Physics: Conference Series* **1343** 012199 ISSN 1742-6596
[10] Fleury J, Lanini M, Pose C, Burnier L, Salvadè A, Zimmermann E, Genoud C and Schüler A 2020 *Applied Physics A: Materials Science & Processing* **126** 417 ISSN 0947-8396
[11] Richner P, Heer P, Largo R, Marchesi E and Zimmermann M 2017 *Informes de la construcción* **69** 3 ISSN 0020-0883
[12] RSRP and RSRQ - Teltonika Networks Wiki