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ScienceDirect

Energy Procedia 122 (2017) 781–786

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Nano & Microstructured Materials for Renewable Energies (Solar Nano and Microtechnologies)

Mobile communication through insulating windows: a new type of low emissivity coating

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Abstract

Building materials attenuate the microwaves used for telecommunication depending on their composition and thickness. Modern windows contain glass with a metallic coating. This might cause a low quality of cell phone reception inside some buildings. In order to improve the transmission of microwaves used for telecommunication through modern glazing, a novel patterned coating was developed. In this work, the morphology and chemical composition of the pattern was characterized. The attenuation to microwaves of coated, uncoated and patterned glass was measured and simulated. The effect of the size of the air gap of a double glazing was studied by numerical simulation. Typical attenuation to the microwaves of building materials used for telecommunications is presented and compared to our newly developed patterned coating. In this paper, we demonstrate that a specific laser treatment on a conductive coating can strongly improve its performances regarding the transmission of microwaves.

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Keywords: Building materials; mobile communication; microwaves propagation; low emissivity coating; laser scribing; energy saving windows.

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10.1016/j.egypro.2017.07.396

1. Introduction

Some building materials attenuate the transmission of microwaves used for mobile communication. Glass in itself is nearly transparent for microwaves. However, when a metallic coating is applied on a glass pane its attenuation increases drastically. This occurs in energy saving windows that contain at least one low emissivity coating made of thin layers of silver and oxides. Mobile communication standards include GSM (Global System for Mobile communication), UMTS (Universal Mobile Telecommunication System) and LTE (Long Term Evolution) using frequencies ranging mainly from 700 MHz to 2.7 GHz. In a building, if the attenuation due to the walls and windows is too strong, the signal inside can be too low [1,2]. One solution is to install repeaters to amplify the signal. However, these active devices consume energy. Another solution is to use Frequency Selective Surfaces (FSS) in order to selectively transmit the wavelengths useful for mobile communication. Kiani et al. [3,4] investigated complex shapes of FSS to transmit narrow frequency bands. However, the proportion of ablated coating is rather large (12.35 % for [4]). Since the high thermal performance of the windows originates from the coating, the ablated surface should be kept as small as possible. Repeaters or narrow band pass FSS need to be replaced frequently unlike conventional building elements, to follow the rapid evolution of communication technologies.

In a previous paper, we demonstrated the possibility to transmit a large band of frequencies including the one currently used for mobile communications through a patterned low-e coating [5]. The global thermal performance of the windows was not influenced [6] for a square patch pattern with 4 % of ablated area. This pattern was made by laser scribing using a nanosecond fiber laser. In this study, we studied the ablated area by Energy Dispersive X-ray (EDX) to observe the repartition of silver after laser ablation. The ablated lines are narrow and not strongly visible, however they can still be observed. Therefore, we decided to evaluate a pattern different from a square or a rectangle, which led to the simulation, fabrication and measuring of triangle patches of low-e coating. Furthermore, the influence of the thickness of the air gap between two glass panes in a double glazing is evaluated by numerical simulations. Finally, a comparison of the attenuation of our newly developed patterned low-e coating with common building materials is presented.

2. Methods

2.1. Fabrication and characterization of the patterned coating

The patterned low-e coating was based on a commercial low-e coating from AGC Verres Industriels Moutiers. Glass samples with a “Low-e Top N+T” coating, a thickness of 4 mm and a size was 500 mm x 500 mm were used. The “Low-e Top N+T” coating contains thin layers of silver and metal oxides such as zinc oxide. Laser ablation of the coating was performed using a 1064 nm nanosecond fiber laser. After laser scribing, the patterned coating was analyzed by Energy-Dispersive X-ray spectroscopy (EDX) with an acceleration voltage of 25 kV. An element mapping of zinc and silver was performed. Then, the processed glass pane was assembled into a double glazing (4 mm of coated glass and 5 mm of grey glass and an air gap of 12 mm) for the measurement of the microwave transmission.

2.2. Measurements and numerical simulation of the microwaves transmission

The determination of the microwave attenuation or RF insertion loss of a material was performed using a free-space approach [7]. The setup is composed of a vector network analyzer Agilent PNA E8364B 10 MHz to 50 GHz with time domain, two High Gain Log-Periodic Antennas 850 MHz to 26.5 GHz and four broadband absorbers. The measured prototype dimensions are 50 cm x 50 cm. For samples smaller than 60 cm x 60 cm, a large metallic shield is used to minimize the edge effect at the panel border. The cancellation of multipath effects of the room is performed by the use of time-gated measurements. More details about this setup can be found in our previous work [5]. The transmission of the microwaves though a double glazing with varying air gap was simulated with the 2.5D EM simulator Ansys® Electromagnetic Suite (release 17). This commercial tool allows fast and accurate simulations over an extremely wide bandwidth.

3. Results

3.1. Characterization of the patterned low-e coating

The principle of the patterned coating is described in Figure 1. The typical U-value, which represents the amount of thermal losses through a window, of a double glazing with no coating (Figure 1 a) is around 3 $W/m^{-2}{\cdot}K^{-1}$. The window is not well insulated; the inside pane is cold in winter and generates discomfort. Radiofrequency waves are almost not attenuated through the windows. Figure b) shows a double glazing with a low-e coating applied on one glass pane (typical U-value around 1.5 $W/m^{-2}{\cdot}K^{-1}$). The long-wave thermal radiation is re-emitted inside thanks to the low emissivity coating. The thermal comfort is improved and large energy savings are obtained. However, the metallic coatings strongly attenuate the radiofrequency wavelengths used for communications. Building materials can also attenuate radiofrequency depending on their composition and thicknesses (see Table 1 in the Discussion section). Mobile signals can therefore be low. Figure 1 c) displays our approach: a double glazing with a low emissivity coating especially patterned by laser ablation to transmit radiofrequency waves.

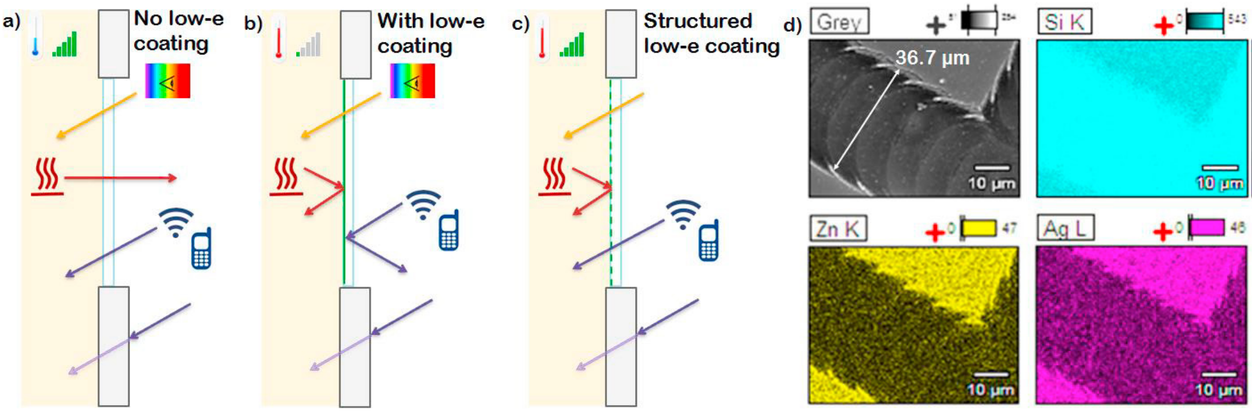

Fig. 1. a) Double glazing without low emissivity coating. b) Double glazing with a low emissivity coating (low-e) applied on one glass pane. c) Double glazing with an innovative low emissivity coating patterned by laser ablation to transmit radiofrequency waves. d) SEM image and EDX element mapping of silicon, zinc and silver at a perpendicular intersection of ablated lines.

Figure 1 d) shows an SEM image of the ablated line along with an EDX element mapping of silicon, zinc and silver. On the SEM image, it can be observed that the ablated width is 36.7 microns. The glass substrate contains Si; it can be seen on the entire image of the element mapping. The low emissivity coating contains Zn, in ZnO and metallic Ag. The element mapping clearly indicates that the low-e coating was ablated on the dark line visible in the SEM image. An accumulation of materials is observed at the edges of the ablated line but no deposition is observed around the intersection point. The pattern is expected to improve the transmission of microwaves because it interrupts the electric conductivity; therefore, short-circuits should be avoided. In this study, the width of the ablated lines was kept between 35 and 40 microns. Hence, the surface of low-e coating removed is inferior to 4 % for a square pattern with 2 mm distance between lines and less than 2 % for an equilateral triangle pattern with a height of 6 mm. This small proportion of coating removed is achieved thanks to the laser ablation with a high precision laser which allows us to obtain very fine lines.

3.2. Measured and simulated attenuation of the microwaves

The measured and simulated attenuation of double glazing made of uncoated glass panes and of double glazing including a square and triangle pattern respectively are displayed in Figure 2 a). The double glazing made of float glass (uncoated) shows a very limited attenuation, smaller than -1.3 dB below 3 GHz. The square pattern is made by ablating lines perpendicular to each other. This pattern results in a square patch of low-e coating of 2 mm x 2 mm.

This corresponds to an ablated area of 4 %. The triangle pattern is obtained by engraving lines with an angle of 60° resulting in patches of equilateral triangles with a height of 6 mm. The ablated area is smaller than 2 %. Figure 2 a) shows that an attenuation lower than 3 dB between 0.85 and 3 GHz can be achieved with the 6 mm height triangle pattern. Expressed in percentage, it means that 60% up to 85% of the signal is now transmitted by the low-e glass, whereas the fully coated glass (standard low-E), which presents a shielding effect larger than 30 dB, transmits only 0.1% of the signal [5]. It can also be observed that the simulation shows a good agreement with the experimental data, which validates the numerical model. This result indicates that not only squares but also triangle patterns can be used.

Figure 2 b) shows a photograph of the coated glass with a triangle pattern. This photograph was taken with a focus on the pattern; still it is not very visible. Thanks to the narrow width of the ablated lines, the patterns are barely visible when looking through the window.

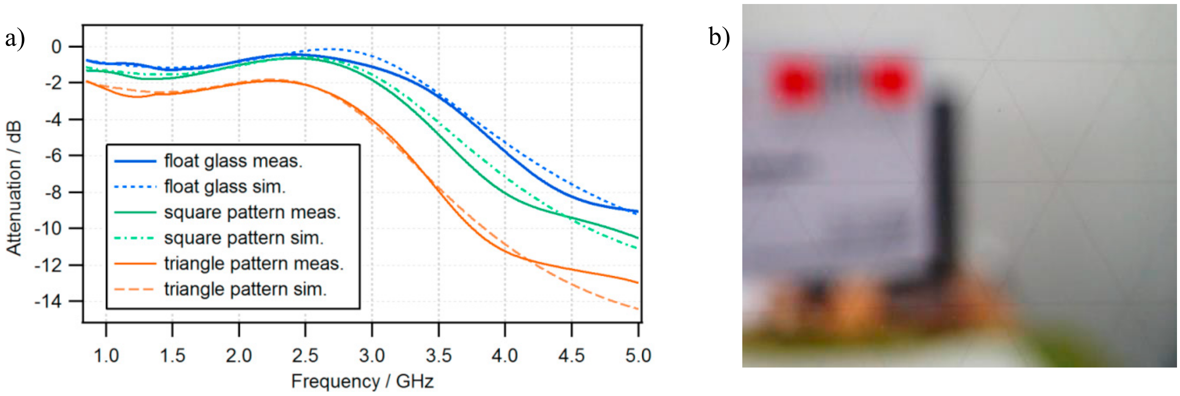

Fig. 2. a) Measured (full lines) and simulated (dashed lines) transmission spectra in the mobile communication range (0.850-5 GHz) for a regular double glazing made of two float glass panes (blue lines) compared to a double glazing with a patterned low-e coating, square (green lines) and triangle (orange lines). b) a photograph of the glazing is focused on the triangle pattern; the pattern is barely visible when looking through the glass.

3.3. Simulation of the influence of the air gap thickness

The transmission of microwaves is not only influenced by the composition of a material but also by reflection and interferences. In order to better understand the transmission of microwaves through a double glazing, simulations with different thicknesses of air gap between the two glass panes were performed. The triangle pattern (height = 6 mm, 2 % of ablated area) was used. The thickness of the air gap was varied between 8 and 16 mm. The results are displayed in Figure 3 and show that the thickness between the two glass panes influences noticeably the microwave transmission. At 2 GHz, a difference of almost 2 dB is observed between the 8 mm and 16 mm thickness, the 16 mm thick air gap giving an attenuation of -1.1 dB. However, at 3.5 GHz, the attenuation is -3.4 dB for the 8 mm air gap and triples for the 16 mm air gap (-10.6 dB).

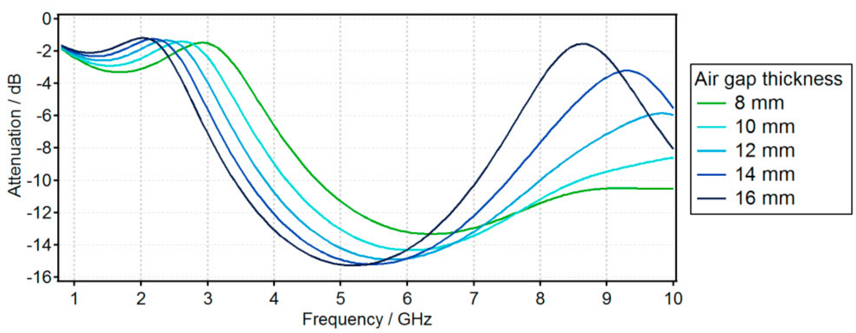

Fig. 3. Influence of the air gap thickness (distance between two glass panes) on the attenuation from 1 to 10 GHz.

4. Discussion

Materials used in building construction attenuate the microwaves more or less depending on their composition and thicknesses. When the U.S. National Institute of Standards and Technology (NIST) [8] performed an extensive measurement campaign on numerous construction materials in 1997, low-e coated glass was not as widespread as today and was not measured. Asp et al. [2] have studied the radio signal propagation in modern residential buildings. They measured the attenuation of insulation materials with and without metallic foil as well as coated glass [2]. In a previous study [5], we studied the impact of a square grid pattern with different sizes and compared it to regular float glass and coated glass. In this work, a new triangle pattern (6 mm height, 2 % of ablated coating) was fabricated and measured. Furthermore, the influence of the thickness of the airgap on a double glazing with this triangle pattern was simulated. The attenuation of common building materials, also called shielding effect, along with our results on patterned low-e coating are reported in Table 1.

Table 1. Comparison of the attenuation of common building materials and patterned low-e coating

			Shielding effect / dB		
	Material	Source	900 MHz	1800 MHz	3 GHz
Construction material	Plywood (dry) 19 mm	[8]	-0.7	-1.2	-0.9
	Lumber (dry) 114 mm	[8]	-2.8	-6.4	-13
	Brick 178 mm	[8]	-5	-7	-16
	Masonry block 203 mm	[8]	-8	-11	-15
	Concrete 203 mm	[8]	-23	-28	-47
	Reinforced concrete 203 mm + metallic grid 70 mm	[8]	-30	-35	-53
Insulation Material	Glass wool 100 mm	[2]	~0	~0	~0
	Polyurethane insulation board 100 mm	[2]	~0	~0	~0
	Polyurethane insulation board with aluminium 100 mm	[2]	-23	-34	-35
Glazing	Glass pane 6 mm	[8]	-0.8	-1.3	-1.9
	Double glazing 4 mm/air 12 mm/5mm	[5]	-0.8	-1.1	-1.2
	Double glazing with commercial low-e 4 mm coated/air 12 mm/5mm	[5]	-30.6	-26.8	-27
	Double glazing with 2 coated glass	[2]	-23	-30	-36
Glazing with patterned low-e	Double glazing with square pattern (4 %) low-e coating 4 mm coated/air 12 mm/5mm (measured)	[5]	-1.3	-1.3	-1.9
	Double glazing with triangle pattern (2 %) low-e coating 4 mm coated/air 12 mm/5mm (measured/*simulated*)	This work	-2.0/*-2.0*	-2.3/*-2.2*	-4.0/*-3.9*
	Double glazing with triangle pattern (2 %) low-e coating 4 mm coated/air 8 mm/5mm (*simulated*)	This work	*-2.1*	*-3.2*	*-1.5*
	Double glazing with triangle pattern (2 %) low-e coating 4 mm coated/air 16 mm/5mm (*simulated*)	This work	*-1.8*	*-1.4*	*-7.1*

The results displayed in Table 1 indicate that most non-metallic materials have a low attenuation (or shielding effect) to the transmission of the microwaves. Only concrete presents a strong attenuation even when it is not reinforced with a metallic grid. This could be explained by its high density. For comparison, a masonry block of the same thickness (with hollow compartments) attenuates 3 times less. A comparison of a polyurethane insulation board with and without aluminum foil was performed by Asp et al. It clearly highlights the influence of the metallic foil on the shielding effect. The insulation board alone is almost transparent to microwaves while one with an aluminum foil shows attenuation levels close to those of 200 mm of concrete. The effect is comparable for uncoated glass compared to glass coated with a low emissivity -hence conductive- coating. Results from our previous studies [5] and from Asp et al. [2] show that coated glass (one or two coated panes) has a strong attenuation, in the same order of magnitude as reinforced concrete or insulation board with a metallic foil. In this study we showed than not only a square pattern but also a triangle pattern could be used to strongly reduce the shielding effect of the coating. The EDX element mapping was used to confirm that the silver is correctly ablated even around the intersection points. Furthermore, the composition of the double glazing, e.g. the thickness of the air gap, also influences the transmission of microwaves due to constructive/destructive interferences on the signal. The thickness of the air gap can be optimized for a specific wavelength. For example, to reduce the attenuation at 2 GHz with the triangle pattern (6 mm), a 16 mm air gap should be used which, in addition, provides the best insulation.

5. Conclusions

In a modern building made of reinforced concrete insulated with an insulation board with a metallic foil and energy saving windows, the signal inside might be too low for mobile communication. In trains the attenuation inside the wagon is even stronger, as , the opaque part of the envelope is metallic. In order to avoid the use, and thus energy consumption and the frequent replacement of repeaters, a passive solution would be preferable. To answer this problem, a patterned low-e coating was developed [5]. The first prototype windows were installed in a train and perform very well both thermally and for microwaves transmission [6]. In this paper, we present an additional effective pattern and detail the influence of the thickness of the air gap in a window. We believe that this development would also be very valuable in the building sector considering the large use of concrete for walls and the number of highly glazed buildings. A post-processing of existing low-e double glazing can be envisioned but the quality control of the ablated lines would be delicate.

Acknowledgements

We gratefully acknowledge the funding institutions: Swisselectric Research SER, Swiss Federal Office of Transport BFV and Prof. P. Oelhafen for initiating the project on the energy efficiency in public transportation. We are also thankful to our industry partners: A. Marguerit, L. Houlmann, N. Noirjean, J. Maushart from AGC Verres Industriels Moutier; N. Dury and and R. Holtz from Class4Laser; C. Isenschmid from BLS.

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