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DETERMINING THE INFLUENCE OF GLASS ELEMENTAL COMPOSITION ON ITS PROTECTIVE PROPERTIES USING LASER-SOUNDING

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Abstract. This study investigates the influence of the elemental composition of industrial window glass on its protective properties against laser-based optoelectronic surveillance. The optical characteristics – transmission and backscattering – were experimentally analyzed using a continuous solid-state laser. The elemental composition of glass samples was determined via X-ray fluorescence spectroscopy. The glass was classified as silicate (quartz), and its components were grouped by functional purpose. The study found that changes in the concentration of amphoteric, nonmetallic, alkaline, and alkaline earth elements significantly affect laser absorption. The results reveal correlations between elemental properties and laser resistance, offering insights for enhancing materials for information protection.

Keywords: chemical elemental composition, silicate glass, X-ray fluorescence analysis, transmittance coefficient, backscattering coefficient, information protection, laser acoustic reconnaissance systems.

1. Introduction

Information security has developed rapidly in recent years, particularly in protecting telecommunications systems, computer software, banking platforms, and digital services. Extensive research has focused on countering hacker attacks and malware, securing financial transactions, and enhancing cryptographic algorithms.[1–3] However, these efforts predominantly address the software and digital domains of cybersecurity.

In contrast, the advancement of technical information protection, particularly physical and optical countermeasures, has progressed considerably more slowly. One of the critical vulnerabilities in this area is the interception of acoustic information via optoelectronic channels, enabling unauthorized access to sensitive data[3]. A primary tool for such attacks is laser-acoustic surveillance systems, which exploit remote detection of surface vibrations induced by sound waves.

A notable demonstration of this threat is the Lamphone[4] technique, first introduced in 2020. It revealed that acoustic waves can cause minute vibrations in objects (*e. g.*, light bulbs), which, in turn, modulate the reflected light intensity. Using high-sensitivity photodetectors, these modulations can be captured and decoded into intelligible audio, allowing real-time eavesdropping.

This issue becomes particularly critical in military settings. During combat operations, laser reconnaissance systems operating in the infrared spectrum can detect the reflections from optical sights and surveillance equipment.[5] Such vulnerabilities highlight the urgent need for effective optical shielding strategies and the development of advanced materials with enhanced protective properties.

Ukrainian researchers have addressed the issue of speech information leakage through optoelectronic surveillance channels.[6] In particular, they proposed a passive protection method involving sunscreen window films. However, experimental results demonstrated that such films do not provide adequate laser radiation shielding and cannot serve as practical anti-laser barriers.

In,[7] copper compound-based films capable of blocking electromagnetic radiation in the ultraviolet and visible infrared ranges were examined. While these coatings showed peak efficiency around 500 nm, their limited spectral coverage significantly reduces their effectiveness against laser scanning systems,[9] which typically operate in the 650–3000 nm range.

Paper[8] explored methods for minimizing window glass vibrations to hinder the reproduction of speech information captured via laser eavesdropping. The study focused on the structural features of insulated glazing units and their influence on laser probing resistance. Results indicated that most vibrations (approximately 99 %) are transmitted through the glass rather than the window frames, highlighting the critical need for enhanced protection of glass components.

Various active methods for protecting speech information have been developed to counter these threats. These include acoustic noise generators, mechanical vibrators, and acoustic shielding devices, as well as techniques based on physical effects – such as magnetostatics, implemented by applying metallic meshes or wire structures to window surfaces, and electrostatics, achieved by coating glass with a continuous metal layer that generates an electric field under applied voltage.[9, 10]

Passive methods of protecting speech information from leakage via optoelectronic channels – particularly laser eavesdropping – have recently garnered growing attention from researchers. These methods involve engineering solutions such as specialized window constructions, using blinds and curtains, and applying functional film coatings. Among these approaches, developing multifunctional films capable of blocking or significantly attenuating laser radiation is considered one of the most promising.

Research in this field has only recently begun to gain momentum, predominantly in applied contexts. Various film materials with highly specialized functions are available on the market, including shockproof, anti-reflective, and blackout films. For example, impact-resistant films such as Kingshield and 3M operate on the principle of multilayer protective glass. They are typically applied to the exterior surface of windows.[11, 12] Anti-reflective films like those produced by Guardian and 3M are designed to absorb and reflect solar and ultraviolet radiation. They are usually installed on the interior surface of glass panes.[13, 14]

Blackout films – such as Gila, SmartTint, and 3M – reduce solar light transmission and exhibit limited absorption of optical radiation.[15–17] Particularly notable are the Signals defense films, which combine blast and impact resistance with the ability to shield against radiofrequency and infrared radiation. These are actively employed in U.S. government facilities to protect confidential acoustic information, particularly as a countermeasure against laser microphones.[18]

A literature review indicates that developing advanced anti-laser film coatings is one of the most relevant areas of passive protection against laser reconnaissance. However, these solutions remain under development and require further investigation, particularly in understanding the relationship between material composition and the ability to absorb or reflect laser radiation.

The military implications of this issue also deserve special attention. Laser scanning systems are increasingly utilized to guide precision weapons targeting military vehicles, drones, and other equipment. Therefore, research into the optical properties of window glass – specifically, its resistance to laser sensing – is particularly relevant in hybrid warfare.[10]

Important indicators characterizing the protective properties of glass and its protective properties against laser acoustic reconnaissance systems are the coefficients of absorption, reflection, transmission, and backscattering. Previously, the influence of absorption and reflection coefficients on the protective properties of the studied glass was established.[10] In contrast, the influence of transmission and backscattering coefficients has not yet been established.

Therefore, this work aims to evaluate the protective properties of widely used window glass samples against laser radiation, focusing on their elemental composition and key performance indicators, namely the transmission and backscattering coefficients of the laser beam. Another aim is to determine the correlation between the chemical composition of glass and its optical behavior.

To achieve this objective, the following scientific tasks were formulated:

– to analyze the elemental composition of window glass samples;

– to measure the transmission and backscattering coefficients of laser radiation;

– to determine the relationship between the chemical composition of glass and its optical properties;

– to evaluate the potential for predicting the protective capabilities of glass through modeling based on its elemental composition.

Preliminary experimental studies conducted by the authors have confirmed the potential of this approach for enhancing the protection of speech information against laser eavesdropping.[10, 19, 20]

2. Experimental

2.1. Materials

The most widely used glass in Ukraine was used in the research, and the list and characteristics are presented in Table 1.

Table 1. List and characteristics of popular glass brands in Ukraine

No.	Glass brand	Coefficient				
		light transmission	reflection	direct solar energy transmission, solar energy	absorption	heat transfer, W/m^2
1	Float glass by Saint-Gobain Glass, SGG Diamant (France)[22]	0.91	0.08	0.88	0.02	–
2	Float glass with a magnetron coating by Guardian of the ExtraClear brand (USA)[23]	0.81	0.12	0.89	0.16	–
3	Euroglas Eurofloat is an uncoated glass made by Euroglas (Germany)[24]	0.89–0.91	0.08	0.83–0.87	0.05–0.10	–
4	Pilkington Optifloat is a float glass made by NSG Group, a sheet glass company operating under the Pilkington brand (UK)[25]	0.75	0.07	0.71	0.44–0.10	–
5	Orionglass is the newest sheet, safety (tempered) glass from Euroglas (Ukraine)[26]	0.89	0.08	0.11	>0.25	5.8

2.2. Methods

The elemental analysis of glass, the most commonly used glass in the Ukrainian market, was carried out using the EXPERT 3L X-ray fluorescence analyzer.[27]

The EXPERT 3L[27] model quantitatively determines elements in any alloy (both standard and non-standard). The EXPERT 3L analyzer can also be used for qualitative and estimated quantitative elemental analysis of various types of non-metallic samples (polymeric and lubricants, construction materials, ores, minerals, and other objects of natural and artificial origin, *etc.*). If there are appropriate standards for the chemical composition of these objects, their precise quantitative analysis can be performed.[27]

It is worth noting that the EXPERT 3L X-ray fluorescence analyzer allows you to determine the content of almost all chemical elements in the sample under study. The principle of operation is based on the X-ray fluorescence analysis (XRF) method: the sample is irradiated with X-ray radiation, resulting in the excitation of the atoms, which emit fluorescent (secondary) X-ray radiation. Each element has a characteristic spectrum, which is recorded by the detector.[27]

However, oxygen ($Z = 8$), an element with a very low atomic mass, has fluorescent radiation with too low energy, which is absorbed in the sample itself or the air and is not registered by conventional energy-dispersive XRF detectors, in particular in the EXPERT 3L device. Because of this, the oxygen content cannot be determined directly.

The chemical composition of flat glass is usually given as mass fractions of oxides. For traditional window glass (float glass), the main components are silicon dioxide (SiO_2), sodium oxide (Na_2O), calcium oxide (CaO), aluminum oxide (Al_2O_3), potassium oxide (K_2O), and iron oxide (Fe_2O_3).[28]

In addition to the main components, the composition may include additional oxides that perform a functional role or come as impurities from raw materials, particularly BaO, Ag_2O, MnO_2, and others.[28]

Since XRF analysis does not determine oxygen, this paper presents only the elemental composition of the glass, in the form of the mass fraction of each element, excluding oxygen.

The measurement result is a table of chemical elements detected in the sample and their corresponding mass concentrations with a determination error of 0.01 % by weight. The EXPERT analyzer can analyze samples of substances ranging from natrium (11) to uranium (92).[27]

To measure the intensity of the transmission laser beam and the one that passed through the sample of the laser beam,[28] the installation was assembled according to the optical scheme in Fig. 2.

A Pocket Laser Power Meter 840011 measured the laser beam power.[29] This device has a wavelength measurement range of 400–1100 nm and an accuracy of ±5 %. A continuous-wave semiconductor laser was employed for the experiment. The visible spectrum was selected to allow direct visualization of the laser beam.[29]

The laser source, test sample, and detector D2 were aligned along the same optical axis. Detector D1 was positioned perpendicular to the axis to measure the intensity of the laser radiation reflected from the sample's surface, while detector D2 measured the transmitted power through the sample. All measurements were conducted in a darkened environment to minimize ambient light interference.

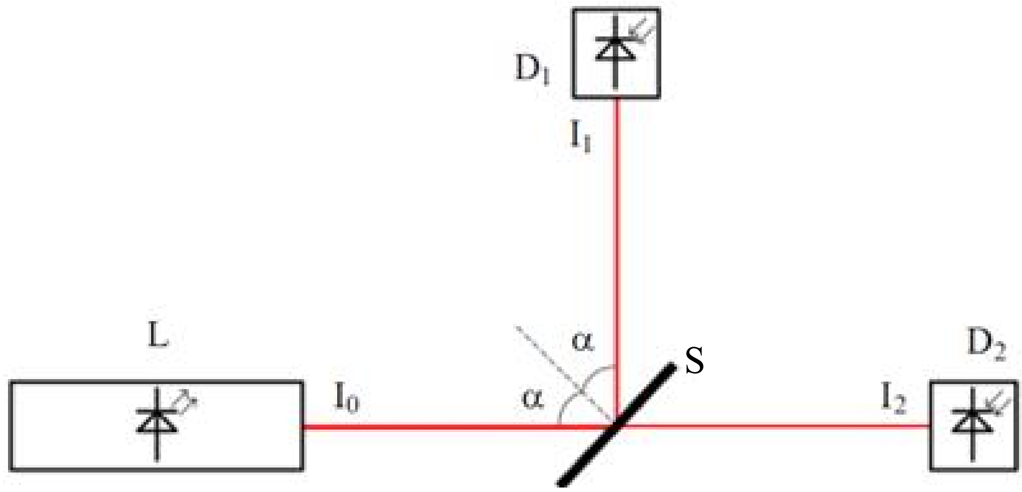

Fig. 1. Optical scheme of installation: *L* – laser; *S* – sample; D_1, D_2 – detector (device for measuring the power of laser radiation)

The ML101U29 laser diode[30] used in this study is a high-power, high-efficiency semiconductor device based on AlGaInP technology. It emits continuous-wave radiation at 660 nm with an output power of 150 mW, operating in a single transverse mode. The measurement error remained within 5 %, which complies with the tolerance requirements for the specified wavelength.[30]

The laser beam's backscattering (K_{bscat}) and transmission (K_{trans}) coefficients were chosen as protection parameters.

The following was measured using the above setup:

– beam transmission power from the test sample;

– backscattering of laser radiation by the sample.

The following was measured using the above setup:

– beam transmission power from the test sample P_{trans};

– backscattering of laser radiation from the sample P_{bscat}.

The backscattering coefficient K_{bscat} is a dimensionless physical quantity that characterizes the ability of a body to scatter the radiation incident on it.

In general, when a parallel beam of radiation propagates in a medium where both backscattering and absorption of radiation coincide, the backscattering coefficient is related to the natural backscattering r' and absorption α' rates by the ratio given below:[31]

$$K_{bscat} = \frac{r'}{\alpha' + r'}\left[1 - e^{-(\alpha' + r')l}\right], \quad (1)$$

where l is the distance the radiation travels in the medium.[31]

The transmission coefficient K_{trans} is a dimensionless physical quantity equal to the ratio of the radiation flux Φ that has passed through the medium to the radiation flux Φ_0 that has fallen on its surface:[31]

$$K_{trans} = \frac{\Phi}{\Phi_0}. \quad (2)$$

In general, the value of the transmission coefficient K_{trans} of a body depends on the properties of the body itself, as well as on the angle of incidence, spectral composition, and polarization of the radiation; numerically, the transmission coefficient is expressed in fractions or percentages.

3. Results and Discussion

To make the tables and dependencies easier to understand, all glass types have been assigned the following designations:

– SAINT-GOBAIN, 3 mm thick – S3;
– SAINT-GOBAIN, 4 mm thick – S4;
– SAINT-GOBAIN, 6 mm thick – S6;
– ORION-GLASS, 4 mm thick – O4;
– ORION-GLASS, 6 mm thick – O6;
– Guardian, 6 mm thick – G6;
– Euroglas, 4 mm thick – Eu-4;
– Pilkington, 4 mm thick – P-4.

Tables 2–4 present the elemental composition of the studied types of glass and their wt. % content, determined by X-ray fluorescence analysis.

Table 2. Elemental (Si, Ca, Fe, Na, S, S, Ti, Sr, Zr, Sn) and quantitative composition of the investigated window glass (n/d – not detected), %

Glass	Elemental composition								
	Si	Ca	Fe	Na	S	Ti	Sr	Zr	Sn
S-4	54.946	41.257	0.502	1.831	0.482	0.129	0.066	0.022	0.028
S-6	55.248	41.427	0.476	2.251	0.372	0.101	0.066	0.027	0.024
O-6	67.28	29.478	0.785	2,037	n/d	0.248	0.03	0.041	0.047
O-4	78.318	21.127	0.185	n/d	n/d	n/d	0.021	0.054	0.024
S-3	54.189	41.257	0.551	3.117	0.614	0.076	0.038	0.02	0.043
P-4	56.752	37.136	0.586	2.149	0.466	0.094	0.046	0.027	0.023
Eu-4	55.058	38.454	0.569	2.408	0.589	0.071	0.044	0.028	0.044
G-6	57.349	37.108	0.482	2.378	0.321	0.085	0.057	0.019	0.022

Table 3. Elemental (Mg, Ni, Rb, Y, Nb, Ag, Sb, I, As) and quantitative composition of the investigated window glass (n/d – not detected), %

Glass	Elemental composition								
	Mg	Ni	Rb	Y	Nb	Ag	Sb	I	As
S-4	n/d	0.004	n/d	0.004	0.004	n/d	n/d	n/d	n/d
S-6	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	0.003
O-6	n/d	n/d	0.021	0.008	n/d	n/d	n/d	n/d	n/d
O-4	n/d	n/d	n/d	n/d	n/d	n/d	n/d	0.03	n/d
S-3	n/d	0.005	n/d	n/d	n/d	n/d	0.024	0.027	n/d
P-4	2.695	n/d	0.004	0.004	0.004	n/d	n/d	n/d	n/d
Eu-4	2.661	0.004	0.004	n/d	0.004	n/d	n/d	0.036	0.002
G-6	2.093	0.004	0.004	0.004	0.005	0.007	0.023	0.039	n/d

Table 4. Elemental (Mn, K, Pb, Br, Cd, Ge, Ba, La, Mo, Zn) and quantitative composition of the investigated window glass (n/d – not detected), %

Glass	Elemental composition									
	Mn	K	Pb	Br	Cd	Ge	Ba	La	Mo	Zn
S-4	n/d	n/d	0.009	n/d	0.015	0.002	n/d	n/d	n/d	0.003
S-6	n/d	n/d	0.004	n/d	n/d	n/d	n/d	n/d	n/d	n/d
O-6	n/d	n/d	0.018	0.003	n/d	n/d	n/d	n/d	n/d	0.006
O-4	n/d	n/d	0.008	n/d	n/d	n/d	n/d	0.068	n/d	n/d
S-3	0.029	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	0.002
P-4	n/d	n/d	0.007	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Eu-4	0.012	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
G-6	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d

As an amorphous inorganic material, glass is mainly based on a silicate network formed by silicon (Si), the main structural component. Other elements introduced into the glass composition, such as impurities, stabilizers, fluorinators, or color agents, come from various mineral sources and technological additives that provide the required properties of the final product.[32–34]

Silicon (Si), in silica (SiO_2), is usually extracted from quartz sand, the primary raw material for glass production. This element forms a three-dimensional network with oxygen, giving glass strength and transparency. Calcium (Ca), usually in the form of oxides (CaO), comes from limestone rocks and acts as a stabilizer, reducing brittleness and increasing the chemical resistance of glass. Similarly, magnesium (Mg) and barium (Ba) are introduced to increase heat resistance and mechanical strength.[32–34]

Alkali metals such as sodium (Na) and potassium (K) are usually obtained from soda or potash salts. They act as fluorinators, significantly lowering the melting point of the silicate mixture, which contributes to energy efficiency in production. However, increasing their content can worsen the chemical stability of the glass.[32–34]

Iron (Fe), manganese (Mn), nickel (Ni), titanium (Ti), molybdenum (Mo), cadmium (Cd), lead (Pb), silver

(Ag), niobium (Nb) and other transition and heavy metals are added to the glass either as impurities in the raw material or as special additives to adjust the optical and color properties. In particular, Fe and Mn are often responsible for the color shade from green to purple, while Cd, Pb, and Ag are used to create rich yellow, red, or transparent optical effects.[32–34]

Solid oxides of zirconium (Zr), titanium (Ti), niobium (Nb), and yttrium (Y) act as structural stabilizers, improving the mechanical strength, chemical resistance, and thermal stability of glass. Germanium (Ge) is used as a structural modifier to improve optical properties, particularly in special types of optical glass.[32–34]

Sulfur (S), iodine (I), bromine (Br), and arsenic (As), although present in small quantities, can perform specific functions as color agents or affect chemical stability, but are sometimes toxic impurities that require control.[32–34]

Thus, the origin of these elements in glass is complex – from natural mineral sources to technological additives – and each plays a decisive role in shaping the physicochemical and optical properties of the final material. Careful dosage and control of the composition allow the creation of glass materials with the necessary characteristics for various applications – from construction to high-tech optical and electronic systems.[32–34]

The calculated protection parameters (1), (2) were taken by a laser scanning device and presented in Figs. 2 and 3.

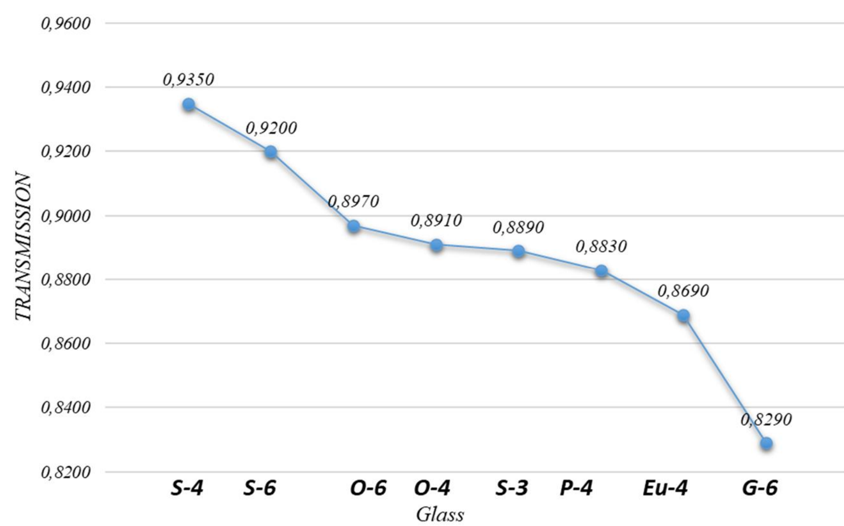

Fig. 2. Determination of transmission coefficient K_{trans} in the tested window glass samples

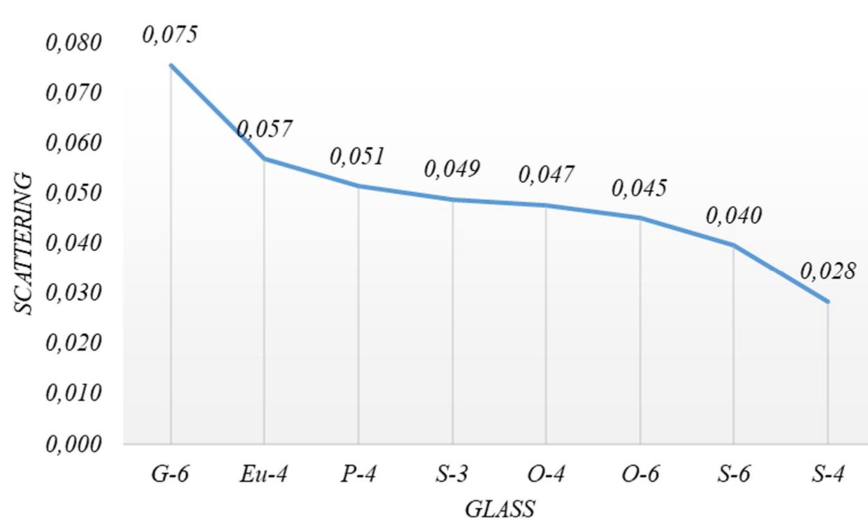

Fig. 3. Determination of the backscattering coefficient K_{bscat} in the tested window glass samples

Figs. 2 and 3 show the change in transmission and backscattering coefficients according to the type of glass. Therefore, based on the elemental and quantitative composition of the existing studied window glass (Tables 2–4) and security parameters (Figs. 2–3), let's present in Tables 5,6 protective characteristics (transmission-backscattering) in accordance with the qualitative and quantitative characteristics according to the periodic table.

Table 5. Relationship between transmission and backscattering coefficients and the elemental composition of the studied glass according to the periodic table of chemical elements (by periods)

Glass	Transmission coefficient, K_{trans}	Backscattering coefficient, K_{bscat}	Elemental composition			
			3 period	4 period	5 period	6 period
S-4	0.935	0.028	[Na Si S]	[Ca Ti Fe Ge Ni Zn]	[Sr Y Zr Nb Cd Sn]	[Pb]
S-6	0.920	0.040	[Na Si S]	[Ca Ti Fe As]	[Sr Zr Sn]	[Pb]
O-6	0.897	0.045	[Si]	[K Ca Ti Fe Zn Br]	[Rb Sr Y Zr Sn]	[Pb]
O-4	0.891	0.047	[Si]	[Ca Fe]	[Sr Zr Sn I]	[La Pb]
S-3	0.889	0.049	[Na Si S]	[Ca Ti Mn Fe Ni Zn]	[Sr Zr Sn Sb I]	
P-4	0.883	0.051	[Na Mg Si S]	[Ca Ti Fe Zn]	[Rb Sr Y Zr Nb Sn]	[Pb]
Eu-4	0.869	0.057	[Mo Na Si S]	[Ca Ti Mn Fe Ni As]	[Rb Sr Zr Nb Sn]	
G-6	0.829	0.075	[Na Mg Si S]	[Ca Ti Fe Ni]	[Rb Sr Y Zr Nb Ag Sn Sb I]	

Table 6. Relationship between transmission and backscattering coefficients and the elemental composition of the studied glass according to the periodic table of chemical elements (by groups)

Glass	Transmission coefficient, K_{trans}	Backscattering coefficient, K_{bscat}	Elemental composition							
			1 group	2 group	3 group	4 group	5 group	6 group	7 group	8 group
S-4	0.935	0.028	[Na]	[Ca Sr] [Zn Cd]	[Y]	[Si Ge Sn Pb] [Ti Zr]	[Nb]	[S]		[Ni]
S-6	0.920	0.040	[Na]	[Ca Sr]		[Si Sn Pb] [Ti Zr]	[As]	[S]		[Fe]
O-6	0.897	0.045	[K Rb]	[Ca Sr] [Zn]	[Y]	[Si Sn Pb] [Ti Zr]			[Br]	[Fe]
O-4	0.891	0.047		[Ca Sr]	[La]	[Si Sn Pb] [Zr]			[I]	[Fe]
S-3	0.889	0.049	[Na]	[Ca Zn Sr]		[Si Sn] [Ti Zr]	[Sb]	[S]	[Mn] [I]	[Fe Ni]
P-4	0.883	0.051	[Na Rb]	[Mg Ca Sr] [Zn]	[Y]	[Si Sn Pb] [Ti Zr]	[Nb]	[S]		[Fe]
Eu-4	0.869	0.057	[Na Rb]	[Mg Ca Sr]		[Si Sn] [Ti Zr]	[As] [Nb]	[S] [Mo]	[Mn]	[Fe Ni]
G-6	0.829	0.075	[Na Rb Ag]	[Mg Ca Sr]	[Y]	[Si Sn] [Ti Zr]	[Nb] [Sb]	[S]	[I]	[Fe Ni]

Considering the data obtained earlier[10], it is possible to correlate the obtained values of the studied coefficients. The correlation between the transmission, absorption, backscattering, and reflection coefficients in glass determines its optical and protective properties, including the ability to counteract laser effects. In the general case, the optical properties of glass are described by the law of energy balance, which states that the total fraction of incident radiation equals unity. For example, an increase in the absorption coefficient Kabsorp usually reduces the transmission K_{trans}, since part of the light energy is converted into heat in the glass material. Similarly, increasing the backscatter K_{bscat} or the reflection K_{refl} also reduces the direct transmission. However, the scattered radiation can be partially redirected back or to the side, which affects visibility and thermal load. In the context of the protective properties of glass, for example, in protection against laser data capture, several interrelated factors play an important role. Thus, a high laser absorption coefficient contributes to converting laser energy into heat in the glass, reducing the intensity of the transmitted beam, which can prevent damage to sensors and optical systems. However, excessive local heating can lead to thermal stress or cracks in the glass. Structural or nanoscale light scattering allows the laser energy to be distributed in different directions, reducing the concentrated intensity of the beam. This mechanism is particularly effective for protection against coherent sources such as lasers, where a directed beam can be harmful. Partial reflection at the glass surface reduces the amount of energy penetrating. In multilayer systems with special coatings, reflectivity can be optimized to maximize laser beam reflection without significantly reducing human visibility. Controlled reduction in transmission, combined with increased absorption and scattering, allows for a balance between visibility and protection from laser exposure.

Thus, to create optically protected glass, it is necessary to consider the complex interaction of these factors. Materials with an optimized balance between absorption, backscattering, and reflection can effectively reduce the intensity of the transmitted laser beam without critically reducing the visibility and functional characteristics of optical systems.

Several key conclusions can be drawn from the research. Firstly, there is no dependence between the transmittance and backscattering coefficients and the thickness of the glass. Secondly, as shown in Tables 5 and 6, there is a direct relationship between the elemental composition of the glass under study and its optical characteristics – transmittance and backscattering coefficients.

The increased concentration of alkaline and alkaline-earth elements in glass directly affects its structural and optical properties, determining the material's resistance to intense laser radiation. Na^+, K^+, Ca^{2+}, Mg^{2+}, and others act as glass modifiers, disrupting the continuity of the tetrahedral silicate network (SiO_4) and forming non-bridging oxygen bonds (≡Si–O⁻), which in turn changes the polarization of the medium and contributes to a more uniform dispersion of laser energy.[35–37] Alkali and alkaline earth cations stabilize oxygen sites, reducing the formation of electron traps and defects (color centers) that could absorb laser radiation and contribute to local overheating.[35, 36] Thanks to Ca^{2+}, Mg^{2+}, and Ba^{2+} ions, glass has higher thermal stability and resistance to thermal shock. It makes it possible to prevent the formation of microcracks and melting under the influence of a pulsed or continuous laser. Highly polarized ions (Ba^{2+}, Sr^{2+}) increase the refractive index of the glass, which can lead to partial reflection or scattering of part of the laser beam, reducing the effective energy absorption.[35–37] Thus, the increased content of alkali and alkaline earth elements in the glass acts in a complex way: it changes the structure of the silicate network, reduces the number of defect centers, increases heat resistance, and modifies the optical characteristics of the glass.

In particular, it was found that chemical elements that increase the transmittance simultaneously reduce the backscattering and vice versa, which indicates the critical role of the internal electronic structure of the elements in shaping the optical properties of glass.

As a result of the studies, an inverse relationship between the transmittance and backscattering coefficients was confirmed, *i. e.*, the higher the transmittance, the lower the backscattering, and *vice versa*. Given the prospects for applying the results obtained in cybersecurity, it can be proposed to purposefully increase the backscattering coefficient by adding appropriate chemical elements to the glass composition, which allows for more effective protection of premises from laser acoustic reconnaissance systems.

The highest level of internal backscattering, K_{bscat}=0.075, was demonstrated by the Guardian glass sample with a thickness of 6 mm. Its elemental composition has a higher concentration of alkaline and alkaline earth metals, determining the increased backscattering ability. It allows us to conclude that the periodic system's elements of groups I and II contribute to increased backscattering. In addition, the presence of silver ions or atoms further enhances this effect.

As a result, the transmission coefficient decreases, which increases the level of protection of the internal space from laser radiation. This effect is manifested in the direction of the beam's forward passage and the opposite (reflected) direction.

4. Conclusions

It has been established that Guardian sheet glass with a thickness of 6 millimeters (K_{trans}=0.829; K_{bscat}=0.075) has proven to be the best protection for secret rooms against laser scanning, which is the primary means of reading information in laser acoustic reconnaissance systems. At the same time, a sample of Euroglass *(K_{trans}=0.869; K_{bscat}=0.057)* with a thickness of

4 millimeters, respectively, also has good transmission and backscattering coefficients. These samples contain significant chemical elements from the alkali and alkaline earth metals group (groups 1–2 of the periodic table), which is key in increasing the backscattering coefficient.

However, the higher the backscattering coefficient, the more difficult it is for attackers to intercept the reflected laser beam. As the backscattering coefficient increases, the transmittance coefficient decreases, which impacts the protection of premises in which restricted information circulates.

Given the above, it can be argued that, based on the results of determining the qualitative and quantitative characteristics of window sheet glass, it is possible to accurately predict its protective indicators and properties that can affect the protection of premises from the leakage of secret information through laser acoustic reconnaissance systems.

To increase the resistance of glass to laser radiation, it is advisable to ensure a balanced presence of oxides of alkali and alkaline earth elements, which modify the silica network, form non-bridging oxygens, and control the degree of polymerization, which optimizes the mechanical and thermal properties of the material. Calcium, magnesium, and barium increase structural stability, reduce the likelihood of defect centers, and improve heat dissipation, which is critical for preventing thermal destruction under the influence of intense laser flux, while alkaline elements, such as sodium and potassium, regulate optical transparency and polarization, provided that their concentration is controlled to avoid excess defects. An additional protective effect is provided by the introduction of transition and rare-earth elements in the form of oxides, which perform the functions of centers of absorption or scattering of laser energy: titanium, zirconium, and niobium oxides increase resistance to photon-induced damage, and the inclusion of strontium or lanthanum reduces permeability for high energy densities. Thus, the formation of glass with a balanced content of modifiers and stabilizers ensures a reduction in the accumulation of defects and creates a mechanism of passive energy dissipation, which makes the material suitable for operation under conditions of intense laser irradiation.

It has been established that to create optically protected glass, it is necessary to take into account the complex interaction of absorption, transmission, reflection, and backscattering coefficients, because glasses with an optimized balance between absorption, backscattering, and reflection can effectively reduce the intensity of the transmitted laser beam without critically decreasing the visibility and functional characteristics of optical systems.

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ВИЗНАЧЕННЯ ВПЛИВУ ЕЛЕМЕНТНОГО СКЛАДУ СКЛА НА ЙОГО ЗАХИСНІ ВЛАСТИВОСТІ ЗА ДОПОМОГОЮ ЛАЗЕРНОГО ЗОНДУВАННЯ

Анотація. *У дослідженні вивчено вплив елементного складу промислового віконного скла на його захисні властивості від лазерного оптоелектронного спостереження. Оптичні характеристики – пропускання та зворотного розсіювання – експериментально проаналізовано за допомогою безперервного твердотільного лазера. Елементний склад зразків скла визначено за допомогою рентгенівської флуоресцентної спектроскопії. Скло класифіковано як силікатне (кварцове), а його компоненти згруповано за функціональним призначенням. Дослідження показало, що зміни концентрації амфотерних, неметалевих, лужних і лужноземельних елементів істотно впливають на поглинання лазера. Результати виявляють кореляції між властивостями елементів і стійкістю до лазера, що дає підстави для вдосконалення матеріалів для захисту інформації.*

Ключові слова: *хімічний елементний склад, силікатне скло, рентген-флуоресцентний аналіз, коефіцієнт пропускання, коефіцієнт зворотного розсіювання, захист інформації, лазерні акустичні системи розвідки.*