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Study of the properties of Absorption and Transmission of Borax glass and windows glass coated by Vanadium oxides by using Helium Neon (He – Ne) laser

A thesis submitted in partial fulfillment for the requirements Of Master (M. Sc.) degree in solid state physic

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الآيـة

بسم الله الرحمن الرحيم

(وَوَرِثَ سُلَيْمَانُ دَاوُودَ وَقَالَ يَا أَيُّهَا النَّاسُ عُلِّمْنَا مَنْطِقَ الطَّيْرِ وَأُوتِينَا مِنْ كُلِّ شَيْءٍ إِنَّ هَذَا لَهُوَ الْفَضْلُ الْمُبِينُ (16) وَحُشِرَ لِسُلَيْمَانَ جُنُودُهُ مِنَ الْجِنِّ وَالْإِنْسِ وَالطَّيْرِ فَهُمْ يُوزَعُونَ (17)حَتَّى إِذَا أَتَوْا عَلَى وَادِ النَّمْلِ قَالَتْ نَمْلَةٌ يَا أَيُّهَا النَّمْلُ ادْخُلُوا مَسَاكِنَكُمْ لَا يَحْطِمَنَّكُمْ سُلَيْمَانُ وَجُنُودُهُ وَهُمْ لَا يَشْعُرُونَ(18) فَتَبَسَّمَ ضَاحِكًا مِنْ قَوْلِهَا وَقَالَ رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَى وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضاه وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ (19))سورة النمل

صدق الله العظيم

Dedication

I would like to dedicate this research to my:

Mother

Father

Brothers in God

Sister

Teachers

Friends

Collogues

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At the first and the last all my thanks to Allah my lord and the owner of everything, who gave me the chance to do this work and made everything easy when it was difficult. My deep thanks to my supervisor Dr. Mohammoud Hilo for his encouragement, guidance, support, suggestions throughout this research project. And Special thanks to Majdi. And also extend thanks to all who help me. I am greatfuly and thanks very much my mother. Also extend thanks to Dr. Hay deer of department of ceramic. Also extend thanks to Dr. Ali of University of Kordofan. At last

I would like to thanks my parents for love, and prayers.

ABSTRACT

This research studied the glass optical properties for two typesof glass, the unique characteristics which classify each type; also it shows the ability of improving the physical optical properties, such as transmission and absorption of light laser as example through out the windows glass coated by vanadium oxides, and Borax glass.

It found that, the glass of windows coated by vanadium oxides, and Borax glass, which fabricated within this research, both of them, give better results in improving some physical properties, compared to the other types of glass, although that the inversely proportional relation between the glass thickness and light transmission dose not change .

ملخص البحث

تناولهذاالبحث خصائص الزجاج الضوئية ، لنوعين من الزجاج والمميزات التي يتصف بها كل نوع وتطرق إلى إمكانية تحسين الخصائص الفيزيائية الضوئية (البصرية) كالامتصاصية والنفاذية لأشعة الليزر (كنموزج) من خلال زجاج النوافذ المطلي باكاسيدالفاناديوم وزجاج البوراكس .
خلصت هذه الدراسة إلى أن زجاج النوافذ المطلي باكاسيدالفاناديوم وزجاج البوراكس الذي تم صناعته فإن كلاهمايعطي نتائج افضل في تحسين بعض الصفات الفيزيائية مقارنة مع العينتان غير المطلية ، على الرغم من ان العلاقة العكسية بين سمك الزجاج ونفاذية الضوء لم تتغير .

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Chapter One

1.0 Introduction

Not all solids are crystalline in nature, for example, glass has a random arrangement of atoms, an amorphous or non-crystalline solid, (Amorphous solids form occurs when a solid substance is melted at high temperatures and then cooled rapidly).

Glass is composed of combination of different materials oxides. For example silicon oxides mixed with various metal oxides .There are many types and uses of glasses like ceramic used in buildings, flat glass, sheet glass, glass pane or plate glass used in (windows or windshield, optical fiber) and all previous types are have properties such as durability, hardness, strength, brittleness, thermal resistance, density, refractive index and transmitter of visible light [1].

Glass has been produced and used by mankind for thousands of years, and its use as a building façade has developed significantly with technological advancements [2].

The first glass appeared a little over 2,000 years ago and was used to seal off entrances to structures and to perform the main function of glass – letting in light while providing a minimum level of protection against wind, cold and rain. However, the use of glass in buildings did not become widespread until a few centuries ago and it was not until the 20th century that glass performance began to evolve significantly.

In the late 1940, the concept of double glazing to enhance thermal insulation began to develop but its real growth in Western Europe came about in the wake of the energy crises in the 1970. Since then, the development of coated glass, laminated glass and so on has provided high-quality solutions for functions such as solar energy and luminosity control, while coated glass, laminated glass, thermally toughened glass. Today, there is increasing demand for all these functions to be combined in a single type of glass [3].

In the late 1980 when low emissivity (low-e) glass first began to contribute to energy saving through window of a building with low-e properties.

This coating blocks infrared radiation due to heat from outside of the building and almost transparent to the visible light [4].

There last studies; nowadays, many new materials have been investigated for the purpose of their application in transparent electronics devices. Among them, oxides based on Ti, V (Transparent Oxide Semiconductor). Vanadium, as an element, creates many compounds with oxygen, resulting in materials with different structural, optical and chemical properties. Differences between various vanadium oxides depend on their structure which determines their specific properties [5-8].

Several oxides of vanadium transition from a semiconductor or insulating state to a metal phase at a critical temperature. Vanadium dioxide undergoes this transition near 68°C, while V_2O_5 undergoes a similar phase transition near 257°C. During the transition a change in oxide crystal structure is accompanied by large changes in electrical and optical behavior. The numerous potential electronic, optical and optoelectronic device applications which have been suggested have stimulated work on the preparation of thin films by a variety of techniques, including chemical vapor deposition, evaporation, and sputter deposition. This research reviews the optical properties of vanadium oxide coatings and the dependence of film properties on sample preparation [9].

This research was considered new for coating of windows glass by vanadium pent oxide by using helium neon (He – Ne) laser.

The transfer of light in form electromagnetic waves can pass through glass for visible light, ultraviolet, near infrared rays but not pass far infrared rays;

this research intended to improve the ordinary glass used by vanadium pent oxide, addition of different metals oxides.

1.2 Research problem

The problems which discussed within this research is that, the glass transmission or absorption of light can only be controlled by coating, not depending on the glass optical properties, on light characteristics.

1.2 Research objectives

The goal of this research is test of the physical optical properties (Transmission, Absorption) for Borax glass and windows glass coated by vanadium pent oxide.

Improve the ordinary glass by different metals addition.

1.3 Research Hypothesis

This research hypothesizes the followings:

It is possible to produce kind of glass with low heat or transmission and discovered new properties of this glass towards. Besides improving several types of glass by adding elements oxides can control the transmission and absorption of light.

1.4 Research significance

Found a kind of glass with a property of passing light and rejecting infrared is a significant goal of research. So research was training to add a new step in this way.

1.5 Research Methodology (experimental)

In this research, the practical method was added a plied to test the optical physical properties of glass. Beside a complete fabrication and set up for each type under glass studying is mentioned and revised. Also, all steps of the practical were shown in chapter three.

1.6 Lay out of research

This research was consisting of four chapters:

Chapter one was stated for the Introduction, research problem, research objectives, research hypothesis, significance, research methodology and Layout of the research, then **Chapter tow** is the theoretical background and literature review **Chapter three** is methodology **Chapter four** is the research results, calculations, discussion and the conclusion.

Chapter Two Theoretical Back Ground
And Literature Review

2.1 Definition of Glass

Glass is a combination of sand and other minerals that are melted together at very high temperatures to form a material. A form of glass occurs naturally within the mouth of a volcano when the intense heat of an eruption melts sand to form Obsidian, a hard black glassy type of stone. Glass, chemically, is actually more like a liquid, but at room temperature it is so viscous or sticky it looks and feels like a solid. At higher temperatures glass gradually becomes softer and more like a liquid.

Glass is classified as an uniform amorphous solid (non-crystalline) material ,indicating it is a solid in which there is no long – range order of the positions of the atoms. This type of atomic structure occurs when a some what viscous molten material cool to rigid form with out allowing crystallization to form a regular network, that exhibits a glass transition, which is the reversible transition in amorphous materials (or in amorphous regions within semi crystalline materials) from a hard and relatively brittle state into a molten or rubber-like state. Glasses are typically brittle and can be optically transparent.

In science, the term glass is defined in a broader sense, encompassing every solid that possesses a non-crystalline (i.e. amorphous) structure and exhibits a glass transition when heated towards the liquid state. These sorts of glasses can be made of quite different kinds of materials: metallic alloys, ionic melts, aqueous solutions, molecular liquids, and polymers. For many applications (bottles, eyewear) polymer glasses (acrylic glass, polycarbonate and polyethylene terephthalate) are a lighter alternative to traditional silica glasses [10].

2.2 Silicate glass

Glass consists mainly of silica, obtained from the pure sands of the Parengarenga Harbors. This sand is washed and sifted to remove shells, stones and exceptionally large grains of sand, before it is mixed with other materials which control the colors and other properties, and lower the1730 °C melting point of pure silica.

Silica (the chemical compound SiO_2) is a common fundamental constituent of glass. In nature, vitrification of quartz occurs when lightning strikes sand, forming hollow, branching root like structures called fulgurites [10].

Silica can be melted at very high temperatures to form silica glass, which has roughly 96 – 99.5% sio_2 content. Because this glass has a high melting point and does not shrink or expand significantly with changing temperatures, it is suitable for laboratory apparatus and for such objects subject to heat shock as telescope mirrors. The fabrication of silica glass is very difficult and, thus, silica glass is not used in construction industry.

Silicate glass generally has the property of being transparent. Because of this, it has many applications. One of its primary uses is as a light-admitting building material, traditionally as small panes set into window openings in walls, but in the 20th-century often as the major cladding material of many large buildings. Glass is both reflective and refractive of light, and these qualities can be enhanced by cutting and polishing to make optical lenses, prisms, fine glassware, and optical fibers for high speed data transmission by light. Glass can be colored by adding metallic salts, and can also be painted.

These qualities have led to the extensive use of glass in the manufacturing of art objects and in particular, stained glass windows [10].

Most common glass contains other ingredients to change its properties. Barium also increases the refractive index. Thorium oxide gives glass a high refractive index and low dispersion and was formerly used in producing high-quality lenses, but due to its radioactivity has been replaced by lanthanum oxide in modern eyeglasses. Iron can be incorporated into glass to absorb infrared energy, for example in heat absorbing filters for movie projectors, while cerium (IV) oxide can be used for glass that absorbs UV wavelengths [12].

2.3 Classification of constituent oxides

The must determine those properties that import distinguishing characteristics to matter, giving it unique identity.

Physical properties such as weight, volume, color, melting point thermal conductivity, thermal resistance, and transmission and the thermal expansion of the glass describe a substance with out reference to any other substance.

A chemical property such as durability describes the behavior of a substance when it reacts of combines with another substance [1]. The glass composition determines the physical and chemical properties of the glass, and varies therefore for each product/application. Depending on their function, glass forming oxides can be grouped into network formers (for example SiO_2, B_2O_3, P_2O_5), intermediate oxides (for example Al_2O_3, TiO_2, ZrO_2), and network modifiers (for example Na_2O, Ca O, Mg O). Categorized oxides are (1) network formers (2) intermediates and (3) network-modifiers. Oxides other than boric oxide and silica have the ability to form network structures. They are listed in Table.

Table (1.2) Classification of oxides in accordance with their ability to form glasses

Network-formers	Intermediates	Network modifiers
B_2O_3	Al_2O_3	Mg O
SiO_2	Sb2O_3	Li_2O
GeO_2	ZrO_2	B a O
P_2O_5	TiO_2	Ca O
V_2O_5	p b O	Na_2O
As_2O_3	Be O	S r O
Zn O	K_2O	

The following is a list of the more common types of silicate glasses, and their ingredients, properties, and applications:

Fused quartz, also called fused silica glass, vitreous silica glass, is silica (SiO_2) in glass form. Has very low thermal expansion, is very hard and resists high temperatures (1000–1500 °C). It is also the most resistant against weathering (alkali ions leaching out of the glass, while staining it). It is used for high temperature applications such as furnace tubes, melting crucibles.

Soda-lime-silica glass, window glass silica 72% + sodium oxide (Na_2O) 14.2% + lime (Ca O) 10.0% + magnesia (Mg O) 2.5% + alumina (Al_2O_3) 0.6%. Is transparent, easily formed and most suitable for window glass (see flat glass). It has a high thermal expansion and poor resistance to heat (500–600 °C). It is used for windows, some low temperature incandescent light bulbs, and tableware. Container glass is a soda-lime glass that is a slight variation on flat glass, which uses more alumina and calcium, and less sodium and magnesium which are more water-soluble. This makes it less susceptible to water erosion. One is sodium carbonate (Na_2CO_3, "soda"), which lowers the glass transition temperature. However, the soda makes the glass water soluble, which is usually undesirable, so lime (calcium oxide [Ca O], generally obtained from limestone), some magnesium oxide (Mg O) and aluminum oxide (Al_2O_3) are added to provide for a better chemical durability. The resulting glass contains about 70 to 74% silica by weight and is called a soda-lime glass [11]. Soda-lime glasses account for about 90% of manufactured glass.

Image (1. 2): Window glass

Sodium borosilicate glass , (Pyrex) silica 81% + boric oxide (B_2O_3) 12% + soda (Na_2O) 4.5% + alumina (Al_2O_3) 2.0%. Stands heat expansion much better than window glass .Used for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses (e.g. Pyrex) have as main constituent's silica and boron oxide. They have fairly low coefficients of thermal expansion (7740 Pyrex CTE is 3.25×10^{-6}/°C [13] as compared to about 9×10^{-6}/°C for a typical soda-lime glass [14]), making them more dimensionally stable. The lower CTE also makes them less subject to stress caused by thermal expansion, thus less vulnerable to cracking from thermal shock. They are commonly used for reagent bottles, optical components and household cookware.

Image (2.2): (Pyrex) Borax glass

Lead-oxide glass crystal glass silica 59% + lead oxide (P b O) 25% + potassium oxide (K_2O) 12% + soda (Na_2O) 2.0% + zinc oxide (Zn O) 1.5% + alumina 0.4%. Because of its high density (resulting in a high electron density) it has a high refractive index, and increased optical dispersion. Making the look of glassware more brilliant (called "crystal", though of course it is a glass and not a crystal) or flint glass [12]. It also has a high elasticity, making glassware 'ring'. It is also more workable in the factory, but cannot stand heating very well.

Image (3.2): Crystal glass

Alumina silicate glass silica 57% + alumina 16% + lime 10% + magnesia 7.0% + barium oxide (B a O) 6.0% + boric oxide (B_2O_3) 4.0%. Extensively used for fiberglass, used for making glass-reinforced plastics (boats, fishing rods, etc.) and for halogen bulb glass.

Oxide glass alumina 90% + germanium oxide (GeO_2) 10%. Extremely clear glass, used for fiber-optic waveguides in communication networks. Light loses only 5% of its intensity through 1 km of glass fiber [15]. However, most optical fiber is based on silica, as are all the glasses above.

Image (4): Optical glass

Another common glass ingredient is crushed alkali glass or "cullet" ready for recycled glass. The recycled glass saves on raw materials and energy. Impurities in the cullet can lead to product and equipment failure. Fining agents such as sodium sulfate, sodium chloride, or antimony oxide may be added to reduce the number of air bubbles in the glass mixture [11]. Glass batch calculation is the method by which the correct raw material mixture is determined to achieve the desired glass composition.

2.4 Properties of Glass

The properties of glass are mainly governed by factors such as composition of the constituents, state of surface, thermal treatment conditions, dimensions of specimen.

Following are the properties of glass which have made the glass popular and useful

It absorbs, refracts or transmits light.

It has no definite crystalline structure.

It has no sharp melting point.

It is affected by alkalis.

It is an excellent electrical insulator at elevated temperatures due to the fact that glass can be considered as an ionic liquid. The ions are not easily moved at room temperature because of the high viscosity. But when the temperature rises the ions are permitted to flow and thus they will sustain an electric current.

It is available in beautiful colors.

It behaves more as a solid than most solids in the sense that it is elastic. But when the elastic limit is exceeded, it fractures instead of deforming.

It is capable of being worked n many ways. It can be blown, drawn or pressed. But it is strange to note that it is difficult to cast in large pieces.

It is extremely brittle.

It is not usually affected by air or water.

Image (5.2): Glass not affected by air and water

It is not easily attacked by ordinary chemical reagents.

It is possible to intentionally alter some of its properties such as fusibility, hardness, refractive power, etc. to suit different purposes.

Image (6.2): Hardness of glass

It is possible to obtain glass with diversified properties. The glasses may be clear, colorless, diffused and stained.

It is possible to weld pieces of glass by fusion.

It is transparent and translucent. The transparency is the most used characteristic of glass and it is due to the absence of free electrons. For the same reason, it also works as a good

Image (7.2): Transparency of glass

It can thus be easily appreciated that glass, though used for thousands of years, is just beginning to be understood and it is still possible to get a variety of glasses with certain chemical additives. Further investigations are yet in the process for preparing glass with extraordinary unusual characteristics and thus to increase the utility of this unique and complex material.

As a matter of fact, the glass industry has made enormous progress all over the world and the glass has become very cheap and useful to the poor as well [16].

2.4.1 Physical properties of glass

2.4.1.1 Optical properties

Glass is in widespread use largely due to the production of glass compositions that are transparent to visible light. In contrast, polycrystalline materials do not generally transmit visible light [17]. The individual crystallites may be transparent, but their facets (grain boundaries) reflect or scatter light resulting in diffuse reflection. Glass does not contain the internal subdivisions associated with grain boundaries in polycrystals and hence does not scatter light in the same manner as a polycrystalline material. The surface of a glass is often smooth since during glass formation the molecules of the super cooled liquid are not forced to dispose in rigid crystal geometries and can follow surface tension, which imposes a microscopically smooth surface. These properties which give glass its clearness can be retained even if glass is partially light-absorbing and colored [18].

Glass has the ability to refract, reflect, and transmit light following geometrical optics, without scattering it. It is used in the manufacture of lenses and windows. Common glass has a refraction index around 1.5. This may be modified by adding low-density materials such as boron, which lowers the index of refraction, or increased (to as much as 1.8) with high-density materials such as (classically) lead oxide, or in modern uses, less toxic oxides of zirconium, titanium, or barium .These high-index glasses (inaccurately known as "crystal" when used in glass vessels) cause more chromatic dispersion of light, and are prized for their diamond-like optical properties. The reflectivity of a sheet of glass is about 4% per surface (at normal incidence in air), and the transmissivity of one element (two surfaces) is about 90%. Glass with high germanium oxide content also finds application in optoelectronic, for light-transmitting optical fibers. Thermal transmittance defined as the amount of heat passing through the glass , in a steady state, per unit of surface area, for a difference in temperature of 1°C on each side of the glass between the atmospheres,

Thermal conductivity defined as the amount of heat passing per second through a pane 1m thick and with a surface area of $1m^2$ where there is a temperature difference of 1m°C between two surfaces [4].

2.5 Structure

Structure of liquids and glasses as in other amorphous solids, the atomic structure of a glass lacks any long-range translational periodicity. However, due to chemical bonding characteristics glasses do possess a high degree of short-range order with respect to local atomic polyhedral [26].

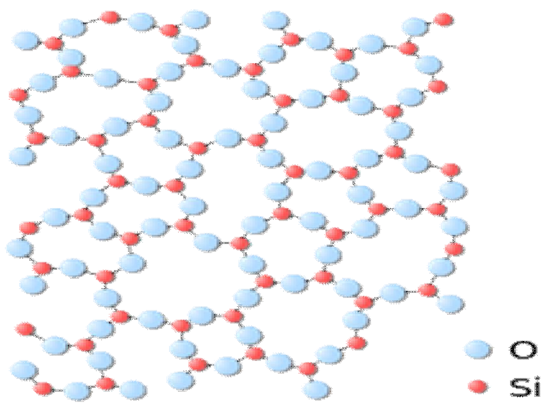


Figure (1.2): Structure of glassy silica

The amorphous is structure of glassy silica (SiO_2) in two dimensions. No long-range order is present, although there is local ordering with respect to the tetrahedral arrangement of oxygen (O) atoms around the silicon (Si) atoms.

American Society for Testing and Materials (ASTM) defines glass as an inorganic product of fusion that has cooled to a rigid condition without crystallizing. The cooling rate can be influenced by a ‘mass effect’ with the chances of glass formation increasing as the size of particle or cross-section decreases. Accordingly, a more precise definition of a glass-former might also specify a minimum mass, say 20 mg, and free-cooling of the melt. As a consequence of their irregular and a periodic network structures, glasses share certain distinctive characteristics. They are isotropic and have properties that change gradually with changing temperature. Bond strengths vary from region to region within the network so that the application of stress at an elevated temperature causes viscous deformation or flow. This remarkable ability to change shape without fracture is used to maximum advantage in the spinning, drawing, rolling, pressing and blowing operations of the glass industry (production of filaments, tubes, sheets, shapes and containers). Glasses do not cleave, because there are no crystallographic planes. Being essentially met stable, the structure of a glass can change with the passage of time. Raising the temperature increases ionic mobility and hastens this process, being sometimes capable of inducing the nucleation and growth of crystalline regions within the glassy matrix. Controlled devitrification of special glasses produces the heat- and fracture-resistant materials known as glass ceramics. Finally, glasses lack a definite melting point. Volume-related property is plotted against temperature for the crystalline and glassy forms of a given substance (Figure (2-1.2)). On cooling, the melt viscosity rapidly increases. Simultaneously, the specific volume decreases as a result of normal thermal contraction and contraction due to structural (configurationally) rearrangement within the liquid. After super cooling below the crystalline melting point, a curved inflexion over a temperature range of roughly 50°C marks the decrease and eventual cessation of structural rearrangement. The final portion of the curve, of lesser slope, represents normal thermal contraction of the rigid glass structure. Shown in (Figure (2-2.2)) Serves as an index of transition; however, it increases in value as the cooling rate is increased. Being disordered, a glass has a lower density than its corresponding crystalline form.

As a liquid is cooled from a high temperature, it may either crystallize (at the melting temperature T_m) or become super cooled; this is shown by the temperature dependence of the specific volume, entropy or enthalpy, under constant pressure, as illustrated in Figure (2.2). The particles (atoms, molecules or ions) forming crystalline materials are arranged in orderly repeating patterns, with elementary building blocks (unit cells) extending to all three spatial dimensions. The structures of crystalline solids depend (predictably) on the chemistry of the material and the conditions of solidification (starting temperature and cooling rate, ambient pressure.), and can be described easily in detail by combining crystallographic notions with diffraction/scattering. Super cooled liquids, on the other hand, demonstrate a rather intriguing behavior. Upon further cooling below the T_m , their particles progressively lose translational mobility, so that around the so-called glass transition temperature (T_g) rearrangement to "regular" lattice sites is practically unfeasible; this behavior is distinctive for the amorphous structures described as glasses or vitreous solids.

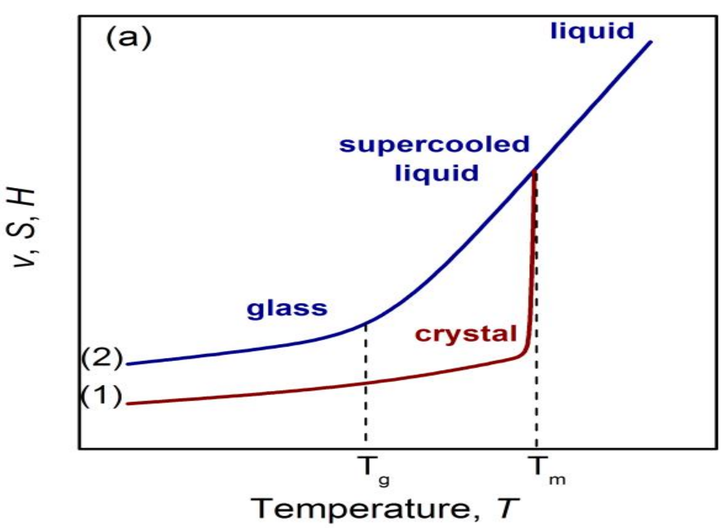


Figure (2.2): Typical temperature dependence of the specific volume (v), entropy (S), or enthalpy (H) of glasses and crystals. Path (1) is not possible in, for example, a tactic polymers lacking a crystalline ordering state.

2.6 Manufacturing Glass

Raw materials are mixed together in a furnace that heats them to 2800 degrees F. As the materials melt and mix together, they float on a bath of molten tin. This is where the term “float glass” comes from.

As the glass comes out of the furnace is slowly cooled and travels down the line on rollers.

As it moves down the line the glass is checked for defects by a laser. Any defects are marked and cut out further down the line in the cutting process

Glass is produced in a two step process, and then shaped to make it suitable for a variety of applications [19].

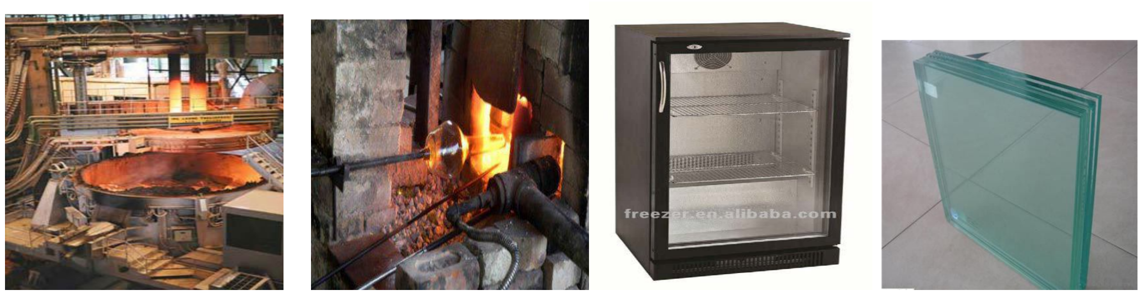
2.6.1 Step 1 - Batch mixing

The mixture of ingredients to make up the glass (silica, Na_2CO_3, $CaCO_3$ and recycled glass, together with small quantities of various other minor ingredients) are mixed in a rotary mixer to ensure an even mix of ingredients and fed into the furnace.

2.6.2 Step 2 - Batch melting

The mixture is heated to 1500-1550 ^{o} C, where the ingredients melt, various chemical reactions take place and CO_2 and SO_3 are evolved.

Shaping plate glass the molten glass is cooled to 1000^{o}C in a drawing canal, and then drawn up a tower (the drawing tower) where it is pressed into the desired width and thickness, and cools to 280^{o}C. Individual plates of glass are snapped off at the top of the tower and further cooled before being put into storage ready for sale [20].



Melting Forming Cooling Finally

Image (8.2): Manufacturing of glass processes

The fundamental composition of structural glass includes high quality sand [21].

Soda-lime glass consists of sand, limestone, soda ash, and cullet (broken glass). The manufacture of such glass is in four phases: (1) preparation of raw material, (2) melting in a furnace, (3) forming and (4) finishing. Figure (3.2) is a diagram for typical glass manufacturing. The products of this industry are flat glass, container glass, and pressed and blown glass polishing. The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass) as required, and is then inspected and prepared for shipment to market. Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet [22].

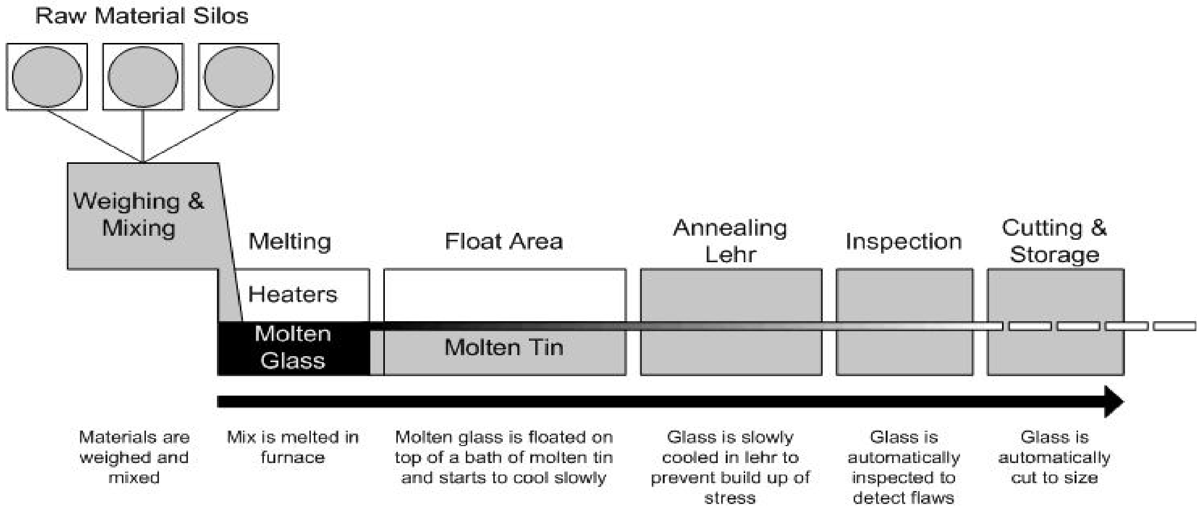


Figure (3.2): shown manufacturing of glass processes

2.6.3 Molding glass containers

The mix of raw materials is dependent on the type of glass desired. Window glass is made from 72% SiO_2, 13% Na_2CO_3 and 12% $CaCO_3$, while bottle glass has more SiO_2 and less $CaCO_3$. Crystal is made from 45% SiO_2 and 44% P b O with 9% K_2CO_3 and Pyrex (used for laboratory equipment and oven wear because of its heat resistance) from 80% SiO_2 and 12% B_2O_3. The remainder in each of these mixtures is made up of the various minors.

The glass batch preparation and mixing, the raw materials are transported to the furnace. Soda-lime glass for mass production is melted in gas fired units. Smaller scale furnaces for specialty glasses include electric smelters, pot furnaces, and day tanks [11]. After melting, homogenization and refining (removal of bubbles), the glass is formed. The top surface of the glass is subjected to nitrogen under pressure to obtain a polished finish [17, 23].

Once the desired form is obtained, glass is usually annealed for the removal of stresses. Surface treatments, coatings or lamination may follow to improve the chemical durability (glass container coatings, glass container internal treatment), strength (toughened glass, windshields), or optical properties (insulated glazing, anti-reflective coating).

2.7 Types of glass

Common types of glass used in residential and commercial buildings and discussed in the following paragraphs.

2.7.1 Clear glass

Clear glass is generally described as transparent and nearly colorless. The primary characteristic of glass in architectural applications is to provide protection from the outside elements, while providing a view and enabling visible light transmittance to the interior. Depending upon its thickness, clear glass allows up to 90% of the visible light, up to 72% of UV (300-400 nm), and up to 83% of solar heat to pass through.

2.7.2 Tinted or heat-absorbing glass

This type of glass contains special color components. The tint is typically specified for its aesthetic properties and for its ability to reduce unwanted solar heat transmission. Commonly used tinted glass may absorb 40%-50% of incoming solar energy, reducing unwanted heat gain. Solar radiation is reflected, transmitted and absorbed by glass. Most of the absorbed radiation is emitted as heat in both directions; some of the absorbed, however, passes through the window by conduction and re-radiation. Tinted glass also has less UV and visible light transmission in comparison to clear glass.

2.7.3 Reflective glass

This type of glass is designed to reflect light and heat, through the use of metal oxide coatings that typically gives the glass a mirror-like appearance. This type of coated glass minimizes unwanted solar heat gain and reduces UV transmission, although visible light transmission is also typically reduced quite significantly. Reflective glass is often specified for commercial buildings. The most commonly used reflective glass in commercial applications will virtually eliminate the ability to see the interior of a building from the outside; an observer will only see their own refection during daylight hours, although exterior views are unimpeded from the building interior. At night however, due to the higher light intensity inside than the outside, the mirroring effect is reversed. An outside observer may see in, but an interior observer may only see his or her own image.

2.7.4 Low-emissivity (low-E) glass

This type of glass has a special surface coating comprised of microscopically thin, optically transparent layers of silver sandwiched between layers of antireflective metal oxide coatings. Low-E glass provides a unique combination of performance attributes, which have led to broad use in Residential and commercial architectural applications. Most low-E coated glass will significantly reduce the loss of generated heat. The most common low-E products also minimize undesirable solar heat gain through a window without the loss of color neutrality and visible light transmission. These Coatings reflect from 40% to 70% of the solar heat that is normally transmitted through clear glass, while allowing the full amount of visible light to pass through. Different types of low-E coatings have been designed

to allow for high, moderate or low solar gain applications, so attention to product specific performance attributes is necessary to achieve the desired effect. UV transmission may also be reduced from approximately 60% down to 20% when comparing a window with standard clear glass to a window containing the most common low-E coated glass. While this is a sizeable reduction In total UV transmission, the majority of the UV radiation being reflected by the low-E coating falls in the UVB range; UVA is largely unimpeded by these otherwise advanced coatings.
Coating or film applied on the inside face of insulating glass that restricts radiant energy (heat) flow. Keeps radiant heat on the same size of glass where it originates depending on coating placement. In this case heat from the sun is kept outside.

2.7.5 Laminated glass

Laminated glass is produced by permanently bonding two pieces of glass together with a tough plastic interlayer (polyvinyl butyric, PVB) under heat and pressure. Once bonded together, the glass sandwich acts as a single unit and generally appears very similar to standard clear glass. The interlayer is virtually invisible when viewed in transmission with glass on either side. The benefit of laminated glass is that if broken, glass fragments will adhere to the PVB interlayer rather than falling free, risk of physical injury and property damage. PVB also has thereby reducing the properties that effectively filter over 99% of UV up to approximately 375 nm without sacrificing visible light transmission, although with new developments, laminated glass is increasingly more transparent to wavelengths above 380 nm. It also reduces transmission of sound. Laminated glass is commonly used in automobiles (for windshields), airports, museums, sound studios, schools, greenhouses, and large public spaces.

2.6.7 Glass ceramics

Image (9.2): Glass ceramics

High - strength glass-ceramic cook top with negligible thermal expansion.
Glass-ceramic materials share many properties with both non-crystalline glass and crystalline ceramics. They are formed as a glass, and then partially crystallized by heat treatment. For example, the microstructure of white ware ceramics frequently contains both amorphous and crystalline phases. Crystalline grains are often embedded within a non-crystalline inter granular phase of grain boundaries. When applied to white ware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime [25].

The term mainly refers to a mix of lithium and alumina silicates that yields an array of materials with interesting thermo mechanical properties. The most commercially important of these have the distinction of being impervious to thermal shock. Thus, glass-ceramics have become extremely useful for countertop cooking [24] [25].

2.8 Different types of insulating glazing

Single-pane glazing is not a high-performance solution in terms of thermal insulation. Various solutions have been developed to enhance the insulating properties of glazing, primarily in the wake of the energy crisis of the 1970s [4]. Insulating glass consists of two or more sheets of glass separated by a hermetically sealed air space. Argon Gas is most commonly used in the airspace most types of glass can be used

2.8.1 Double glazing

The first type of thermally insulating glazing was double glazing, which comprises two sheets of glass separated by a spacer to provide a space filled with dry air. The insulating properties and reduces the thermal transmittance value of the glazing.

Glazing is the process of placing glass into profiles designed to receive them, then held in place with glazing clips, blocks and compounds making a weather tight joint between the glass and frame.

Proper glazing keeps the glass from contacting the frame during thermal expansion of the glass or the frame and during loading due to wind, snow, rain or seismic forces.

2.9 Glass window

Glass windows that are commonly used in buildings can be classified as single pane glass and double pane glass. Glass is also classified according to the type as clear, tinted, reflective and low-e glass. Clear glass and tinted glass are usually referred to the same group according to the manufacturing method. Reflective, low-e and glass applied with film are usually referred to another group. Reflective glass is a clear or tinted glass coated with thin metallic film by using a sputtering technique. Low-e glass is a double pane clear glass or tinted glass with a low emissivity coating on the inner surface of the outer pane glass. Therefore reflective glass and low-e glass are usually defined as special types of glass applied with film. Each type of glass has unique spectral optical properties which varied with the wavelength. The solar radiation has spectral range from about 0.38 to 3.5 μ m. The range of wavelength of the solar radiation spectrum is divided into the visible range (0.38-0.76 μ m) and the infrared range (0.76-3.5 μ m). The spectral optical properties are dependent on the type and thickness of the glass. The spectral optical properties of glass, the transmittance, absorptance and reflectance, are the main properties that affect on the thermal performance of the glass windows. Since the summation of the three properties (transmittance, absorptance and reflectance) is equal to one. One property of glass will affect the other two (i.e. glass with high transmittance will have low absorptance and reflectance). The normal of incidence spectral are transmittance of clear glass and tinted glass [27].

2.10 Vanadium

Vanadium (Z = 23) is a first row transition element and the first element in Group V b of the Periodic Table. It is a hard, steel-grey metal which melts at about 1,700 °C. There are two naturally occurring isotopes: 50V, which decays by electron capture and emission with a very long halflife of 3.9 X 1017 years, and the stable 51 V (99.75%). Vanadium is widely distributed, with an average abundance of 135 mg kg-1 (Mason and Moore, 1982; Adriano, 1986) and ranks 20th in crustal abundance. The important oxidation states are II, III, IV, and V [28].

Smart glass can switch from transparent to opaque at the flick of a switch and is increasingly used in cars, aircraft and homes to reduce the Sun's glare and filter out infrared light and heat. now used vanadium dioxide to make a transparent material that can be activated to block infrared light without affecting its transparency for visible light [31]. Vanadium dioxide is a well-known thermo chromic material that is transparent below about 30 °C and reflects infrared light above 60 °C. This transition is related to a change in crystal structure that also results in a shift from electrically insulating properties at lower temperatures to conductive properties at higher temperatures [30]. In its higher temperature metallic phase (above 67◦C), VO_2 has a tetragonal crystal structure, similar to that of the mineral rutile, with each vanadium coordinated to six nearest oxygen’s, forming octahedral. These octahedral are symmetrical and form edge-sharing chains along the c-axis of the crystal, with the vanadium atoms in a nominal +4 oxidation state. One of the principal features of this lattice is that the c/a ratio is rather small in comparison to other structured compounds, which places adjacent vanadium atoms closer together along the c-axis [31].

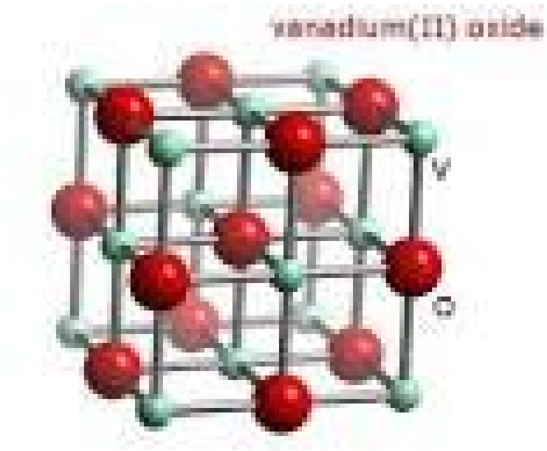


Figure (4.2): structure of vanadium dioxide VO_2

2.10.1 Metal-insulator phase transition (MIT)

When cooled below 67◦C, VO_2 undergoes a sharp and reversible phase transition into a monoclinic crystal structure. The vanadium atoms dimerism, which leads to an alternating structure, properties and applications of vanadium oxides [32].

A schematic of the crystal structures in VO_2, showing the motion of the vanadium (black arrows) with respect to the oxygen ions across the metal-insulator transition. VO_2 acts like an insulator at low temperatures but like a metal at near room temperature [33] .

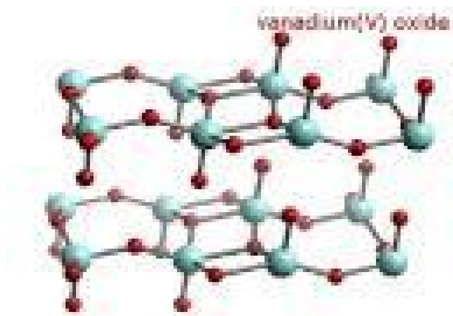


Figure (5.2): structure of vanadium pent oxide V_2O_5

Chapter Three Methodology

3.1 Introduction

This chapter considers very important part of materials and methodology (work applied principle) of devices and ways of measures of properties and optical physical characteristics.

3.2 Devices and Materials used:

Glass samples are composed of materials mentioned here, (silica oxide (SiO_2), sodium carbonate (Na_2 CO_3), calcium carbonate ($CaCO_3$), magnesium oxide (Mg O), aluminum oxide (Al_2O_3),), (Li_2CO_3) lithium carbonate , vanadium pent oxide (V_2O_5) . An Oven with a maximum temperature of 1200 $^\circ$C. this give sensitive Balance to measure mass. Crucible from ceramic, bears high temperature and do not react with the, cup, optical devices (source of laser), sample of windows glass (slights from ordinary windows glass).

3.3 Description of Materials

This procedure always involves selection of raw materials and calculation of the relative proportions of each to use in the batch and weighting.

The materials used in this work consist of glass samples.

The sample of soda lime glass is composition of 20% Na_2 CO_3 _ 70% SiO_2 – 7% Ca CO_3 _ 2% Mg O _ 0.6% AL_2O_3 _ 0.4% Li_2CO_3.

The sample of Borax glass is composition of 50% sand, 40.4% feldspar borax, 1.33% whiting and 7.37 % Microcline.

Table (2.3) Raw materials for glass making

Common Name	Nominal composition	Molecular weight (in g/mol)	Gravimetric factor	Appearance
Alumina	AL_2O_3	102	AL_2O_3	Squished white
Feldspar Borax	Na_2O-$2B_2O_3$-$10H_2O$	381	B_2O_3 = 2.74 Na_2O = 6.14	Squished white
Cullet	Scrap glass	Varies with exact composition	Varies with exact composition	Squished white
Whiting	Ca O_3	56	Ca O = 1.79	Squished white
Soda ash	Na_2CO_3	62	Na_2O = 1.71	Squished white
Microcline	K_2O-AL_2O_3-$6SiO_2$	556	K_2O = 5.91 AL_2O_3 = 5.46 SiO_2 = 1.54	Squished white
Magnesium oxide	Mg O	40.31	Mg O = 1.00	Squished white
Lithium carbonate	Li_2CO_3	73.88	Li_2O = 1.74	Squished white
Sand Or silica oxide	SiO_2	60	SiO_2 = 1.00	

Molecular weights of components (in g mol^{-1})

Molecular weight of glass:

(0.20×106)+(0.70×60)+(0.07×100)+(0.02×40.31)+(0.06×102)+(0.04×73.88)

= 77.8222 g mol^{-1}

Weight fraction of each component

Na_2 CO_3 = (0.20×106) ÷ (77.8222) = 0.2987 g

SiO_2 = (0.70×60) ÷ (77.8222) = 0.581 g

Ca CO_3 = (0.07×100) ÷ (77.8222) = 0.0968 g

Mg O = (0.02×40.31) ÷ (77.8222) = 0.01115 g

AL_2O_3 = (0.06×102) ÷ (77.8222) = 0.0046 g

Li_2CO_3 = (0.04×73.88) ÷ (77.8222) = 0.00409 g

For 20 grams of glass

Na_2 CO_3 = 0.2987× 20 =5.97 g

SiO_2 = 0.581×20 = 11.6 g

Ca CO_3 = 0.0968×20 = 1.94 g

Mg O = 0.01115×20 = 0.22 g

AL_2O_3 = 0.0046× 20 = 0.092 g

Li_2CO_3 = 0.00409× 20 = 0.0818 g

Sample of borax silicate glass

For 100 grams of glass

(Na_2O $2B_2O_3$ $10H_2O$) weight Feldspar borax 40.4grams (K_2O AL_2O_3 $6SiO_2$) weight of Microcline 7.37 grams,(Ca CO_3) weight calcium carbonate 1.33 grams,(SiO_2) weight of sand 50.90 grams.

Table (3.3) properties of laser used in this experiment.

wavelength	632.8 nm
Input voltage	230 V
power	1mw
classification	Second class
Diameter pulse	

3.4 Methodology

Experimental work is to have been done in two different steps:

3.4.1 One step of manufacture glass (Preparation of samples)

Steps used to manufacture glass

3.4.1.1 – Batching

Number different compounds in addition to pure oxides, can be used to form a glass melt .These include of raw materials given above in table.

3.4.1.2 – Mixing and melting

Mixing these are materials to provide a homogeneous.

Then put a mixture each sample inside crucibles melting for sample Soda lime glass and sample borosilicate glass.

Put Samples inside the oven at 170°C temperature, elementary of degree heat. Temperatures were taken every 30 minutes until it was melting all the materials and homogenized with each other at 1080°C

For soda lime glass

$Na_2CO_3 + SiO_2 \rightarrow O\ Na_2.SiO_2 + CO_2$ (g)

$CaCO_3 + SiO_2 \rightarrow CaO.SiO_2 + CO_2$ (g)

$Li_2CO_3 + SiO_2 \rightarrow Li_2O.SiO_2 + CO_2$ (g)

$AL_2O_3 + SiO_2 \rightarrow AL_2O_3.SiO_2$

$Mg\,O + SiO_2 \rightarrow M\,g\,O.SiO_2$

Formation of new eutectic mixture $Na_2.2SiO_2$ at 800° C

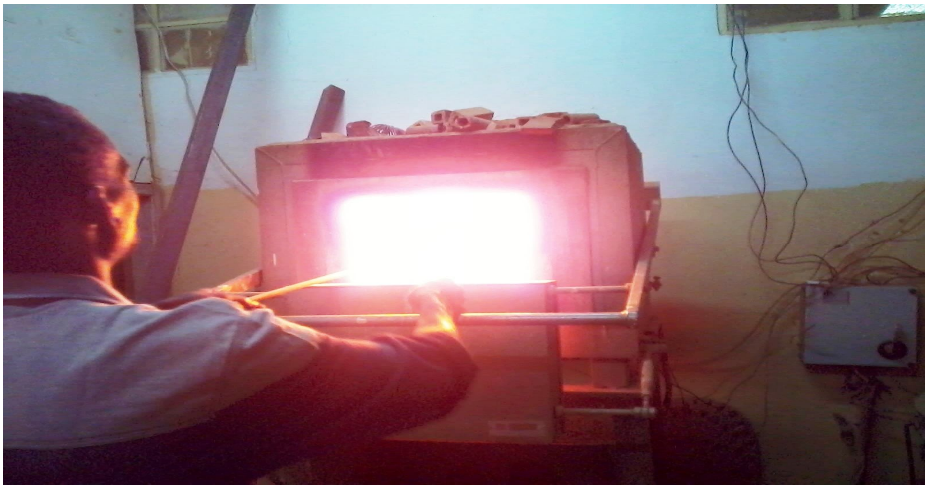


Image (10.3): Melting

3.4.1.3 – Refining

After process the melting. The initial refining and molding of molten (borosilicate) on iron a plate coating for soap and flour to prevent the contiguity; but can not molding of soda lime glass because high temperature needed between (1550 _ 1600) $^\circ$C , the found maximum temperature for oven 1200°C.

Image (11.3): Molding

3.4.1.4 - Conditioning (cooling)

Reduced temperature and start time of sample fast cooling and then the glass

3.4.1.5 – forming

Can be glass is form of (plate or sheet) but can not soda lime (glass windows) form therefore replace samples of soda lime glass (glass windows)

Image (12.3): Borax glass

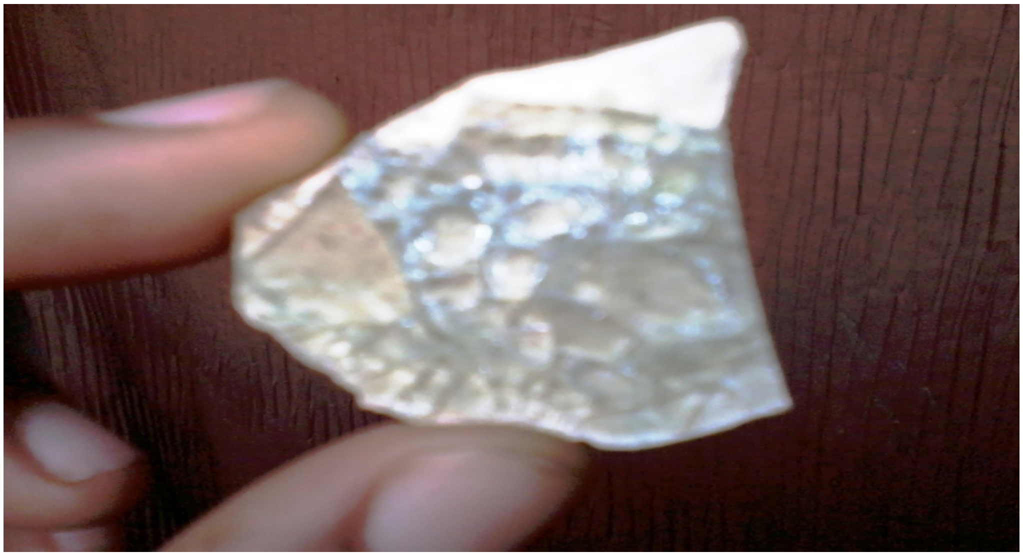


Image (13.3): Soda lime glass (windows glass)

glass windows in the markets proportion to the difficulty of molding and forming a slice of glass that was manufactured and also the lack of an oven at high temperatures until it becomes molten more liquid and less viscous so it has to study the samples ready replaced.

Glass samples are ready to study.

3.4.2 The second step study of the physical properties optical of to samples

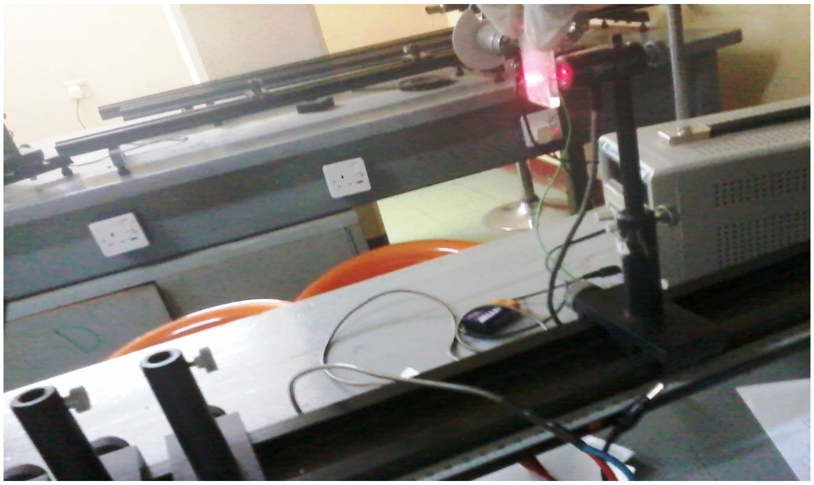


Image (14.3): Laser (He – Ne)

1-Samples were thickness

2 - Reached a circuit electrical to measure both voltage and current to borosilicate glass and glass windows; those are not conductivity because both voltage and current are not reading.

3-Samples of the Light Source offered

4 - study both of transmission and absorption of incidence light radiation on crystals (samples) by ordinary light and laser helium neon (He _ Ne) of wavelength 632.8nm .

Adjust each of the laser and detector, those are contacted of electrical source

I took the normal optical intensity light (I0)

The samples are placed between the detector and source light (laser helium neon or ordinary light) where the sample mode (slice) every time the recorded intensity transmitted light (I) of each sample by Detector

Repeated the experiment for various samples of various thickness a glass.

5 - Results recorded in the chapter four.

Chapter Four Results and Discussion

4.1 Calculations

Results found below each of the absorption coefficient and transmittance light for the glass, when used source light (ordinary light and laser Helium Neon) accordingly laws of the following. Can be finding absorption coefficient by used this equation

$$I = I_0 \exp (\square \alpha\ x)$$

$$(I/I_0) = \exp (\square \alpha\ x)$$

$$\alpha = \square\ (\ln (I/I_0))/x)$$

I = incidence intensity radiation

I_0 = intensity transmittance radiation

(α) = absorption coefficient

x = thickness

$$\square = I/I_0$$

($\square$) = permeability

Table (4.4) Illustrated of temperatures within the oven

Time minute	Temperature (°C)
0	170
30	400
60	520
90	620
120	680
150	740
180	780
210	820
240	870
270	900
300	940
330	990
360	1020
390	1060
420	1080

Table (5.4) calculation of the permeability (transmission) and absorption Coefficient used by above equations

$I = \square$ and $I_0 = 246$

Sample	Thickness (mm)	Permeability (transmission) (□) or (I) = I/I_0	Absorption coefficient (α) = □(Ln(I/I_0))/x
Sodium borosilicate	1.01 1.92 2.318	0.65 0.512 0.545	5.877 3.216 2.637
Soda lime (windows glass)	2.512	0.8699	2.25
Coating glass by vanadium pent oxide	2.512	0.126 0.309 0.244	3.016 2.66 2.75

4.2 Discussion

In this research, the use of vanadium pent oxide coating at glass, besides fabricating of a Borax glass is extended to find anew property of glass within optical and physical characteristics testing. It found that the coating gives a better improving in glass properties especially in the way of passing of the laser light and rejecting the infrared the inversely proportional relation between, glass thickness and light transmission dose not change.

The comparison between ordinary windows glass and coated windows glass by vanadium pent oxide from whereat (absorption coefficient and light transmission), absorption coefficient for windows glass is los than that found by coated glass because of the high transmission of light, at a high values of glass thickness.

4.3 Conclusion

From the above results after conducting the experiment and calculations found the absorption coefficient and permittivity of light or transmission light proportionate inversely with thickness of sample.

4.4 Recommendations

Training scientific and laboratories by all devices and apparatuses

Studies are increased of about the glass and development of manufacturing of the glass

Development of this research for find insulating glass

The benefit from of local raw materials the existing in the Sudan in manufacturing glass.

Reference

[1] Forensic Science Prof. Nehru, CC 30.07 Spring 2007.

[2] Kelly Wheeler, The History of Glass in Architecture, source - www.articledashboard.com

[3] GFF – Das Praxismagazin fur Production und Montage, 2013, p 46

[4] www.yourglass.com, all - about – glass.

[5] MANNING, T. D., PARKIN I. P. Vanadium (IV) oxide thin films on glass and silicon from the atmospheric pressure chemical vapour deposition reaction of VOCL3 and water. *Polyhedron*, vol. 23, p. 3087-3095, (2004).

[6] WANG, X. J., LI, H. D., FEI, Y. J., WANG, X., XIONG, Y. Y., NIE, Y. X., FENG, K. A. XRD and Raman study of vanadium oxide thin films deposited on fused silica substrates by RF magnetron sputtering. *Applied Surface Science*, vol. 177, p. 8-14, (2001).

[7] LEE, S. H., CHEONG, H. M., SEONG, M. J., LIU, P., TRACY, C. E., MASCARENHAS, A., PITTS, J. R., DEB, S. K. Raman spectroscopic studies of amorphous vanadium oxide thin films. *Solid State Ionics*, 2003, vol. 165, p. 111–116.

[8] S. Chaiyapinunt, B. Phueakphongsuriya, K. Mongkornsaksit, and N. Khomporn, "Performance rating of glass windows transmit and glass windows with films in aspect of thermal comfort and heat transmission," Energy and Buildings, vol. 37, pp. 725-738, 2005.

[9] Optical Society of America, (1991).

[10] M. I. Ojovan "Glass Formation in Amorphous SiO2 as a Percolation Phase Transition in a System of Network Defects", JETP Letters 79 (12) 632–634. Bib code: 2004JETPL.79.632O. Dui: 10.1134/1.1790021, 2004.

[11] (a b c B. H. W. S. de Jong, "Glass"; in "Ullmann's Encyclopedia of Industrial Chemistry"; VCH Publishers, Weinheim, Germany, ISBN 3-527-20112-5, pp. 365–432, 1989.

[12] Heinz G. Pfaender (1996), Schott guide to glass, Springer. pp. 135,186, ISBN 978-0-412-62060-7, Retrieved 8 February, 2011).

[13] Corning, Inc. Pyrex data sheet, (PDF), Retrieved on, 2012.

[14] AR-GLASS Schott, N.A., Inc data sheet

[15] Mining the sea sand, Seafriends.org.nz (1994-02-08), Retrieved on, 2012.
[16] http://www.indianconstructionindustry.com/indian_construction_topics/properties_of_glass.html
[17] Michel W. Barsoum, Fundamentals of ceramics, Bristol: IOP, ISBN 0-7503-0902, 2003.
[18] Donald R. Uhlmann, Norbert J. Kreidl, Optical properties of glass. Westerville, OH: American Ceramic Society, ISBN 0-944904-35-1, 1991.
[19] Slide courtesy of Andersen Windows
[20] ACI New Zealand Glass Manufactures, Callan, Louise, looking into glass, new Zealand Geographic, Jan – Mar 1989.
[21] Structural Glass Technology systems and Applications submitted to the Department of civil and Environmental Engineering on June 6th, 2005 or libraries, May 31, 2005.
[22] (J. A. Danielson, ed., Air Pollution Engineering Manual, 2nd Ed., AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, Out of Print, May 1973.
Richard B. Reznik, Source Assessment: Flat Glass Manufacturing Plants,
EPA-600/20-76-032b, U. S. Environmental Protection Agency, Cincinnati, OH, March 1976.
J. R. Schoor, et al., Source Assessment: Glass Container Manufacturing Plants,
EPA-600/2-76-269, U. S. Environmental Protection Agency, Cincinnati, OH, October 1976.
A. B. Tripler, Jr. and G. R. Smithson, Jr., a Review of Air Pollution Problems and Control In The Ceramic Industries, Battelle Memorial Institute, Columbus, OH, presented at the 72nd Annual Meeting of the American Ceramic Society May 1970.
J. R. Schorr, et al., Source Assessment: Pressed and Blown Glass Manufacturing Plants, EPA-600/77-005, U. S. Environmental Protection Agency, Cincinnati, OH, and January 1977.
6. Control Techniques for Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

Confidential test data, Pepco-Environmental Specialists, Inc., cincinnati, OH.
H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PS-293-923, National Technical Information Service, Springfield, VA, emission test data, 1979.
from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 219, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
Environmental assessment , data systems, op. cit. Series No. 223.
Environmental assessment , data systems, op. cit. Series No. 225).
[23] "PFG Glass". Pfg.co.za. Retrieved 24 October 2009.
[24] A b W.D. Kingery; H.K. Bowen, D.R. Uhlmann , Introduction to ceramics (2 Ed.). New York: Wiley, ISBN 978-0471478607, (1976).
[25] A b David W. Richer son Modern ceramic engineering: properties, processing and use in design (2 Ed.). New York, NY: Dekker, ISBN 0-8247-8634-3, (1992).
[26] P. S. Salmon, "Order within disorder". Nature Materials 1 (2): 87–8. Dui: 10.1038/nmat737, PMID 12618817, (2002).
[27] (M. Rubin , K. von Rothay , and R. Pawls "Window optics," Solar Energy, vol. 62, pp. 149-161, 1988. "OPTIC 5," [Online] , Available: http://windows.lbl.gov/materials/optic5/ Accessed: Feb, 2005).
[28]Adriano, D.C. Trace Elements in the Terrestrial Environment, Springer-Verlag Inc, New York, All way, B.J. (Ed), 1990, Heavy Metals in Soils. Blackie & Son Ltd., Glasgow, 1986.
[29] http://phys.org/news/-vanadium-dioxide-smart-glass-block.html#jCp, 2013.
[30] http://phys.org/news/vanadium-dioxide-smart-glass-block.html#jCp, 2013.
[31] Kucharczyk & Niklewski 1979.
[32] Structure properties and MEMS and microelectronic applications of vanadium oxides, pp. 531–542, © Printed in India, Box 352500, Seattle, WA 98195-2500 USA, August 2009.
[33] http://phys.org/news/advanced-source-vanadium-dioxide.html#jCp, 2013.