Al-Nahrain Journal of Science
ANJS, Vol.28(2), June, 2025, pp. 122-138

Transparency of Selected Materials for Infrared Electromagnetic Radiation Band Emitted From Human Body: Practical Test

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Article's Information

Received: 29.04.2024
Accepted: 22.08.2024
Published: 15.06.2025

Keywords:
Infrared
Transparency
Human emitted IR
Graphene
Material infrared transparency
Electromagnetic Radiation

Abstract

Infrared (IR) thermography has recently become an important tool for medical diagnoses. IR thermographic images are acquired directly from a targeted area of the human body. There are some limitations in protecting IR detectors from germ contamination through thermography which is vital to avoid contamination to from affected person to other healthy person. Other limitation is in weight-bearing thermal images. Both of these limitations require finding some material to cover IR detector or to localized between the IR detector and the detecting area, should be transparent to low-power IR emitted by human to avoid losing thermal information. This work aims to test some infrared (IR) transparent materials to find their transparency for low power IR electromagnetic radiations that are emitted from the human body in the range of 8–14 nm for the purpose of medical applications. An IR detector from Sensor Technology, model (iHA417W) with a detecting range of 8–14 microns has been used in this study by localizing several materials between IR source (human body source, and after that gas lighter flame source) and the IR detector to find the material transparency for IR emitted from the body by comparing IR temperature measurements before and after localizing these materials. The results show that among all the tested materials, only graphene (1-layer thickness of 35µm) can transmit IR emitted from the human body at a percentage of 0.67 of the emitted radiation compared to 0.13 of the IR emitted from gas lighter flame. These results conclude that graphene could be used as a cover to protect IR detectors from contamination, but it is not applicable for weight-bearing IR thermography applications because it can't bear the weight of the body without tearing.

http://doi.org/10.22401/ANJS.28.2.12

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1. Introduction

1.1. General Background

Infrared (IR) is a type of electromagnetic radiation, including wavelengths between the 780 nm to 1000 µm. IR is divided into different bands: Near-Infrared (NIR, 0.78~3.0 µm), Mid-Infrared (MIR, 3.0~50.0 µm) and Far-Infrared (FIR, 50.0~1000.0 µm) as defined in standard ISO 20473:2007 Optics and photonics -- Spectral bands [1,2]. Human body emits infrared (IR) electromagnetic radiations in the range of (2 – 14 µm) at emissivity value (ε) of human skin ranges
between $\varepsilon = 0.97$ and $\varepsilon = 0.99$ [3], the most intensity is emitted at (12µm) [4]. In additional to that human

skin temperature typically ranged from 36 °C to 37.5 °C, corresponding to a maximum wavelength of 9.5μm from the skin for the related heat diffusivity [5]. According to that there will be two expected peaks for human IR spectroscopy at 9.5μm and 12μm. The intensity of the infrared radiation emitted by objects is mainly a function of their temperature. In infrared thermography, this feature is used for multiple purposes: as a health indicator in medical applications [6], as a sign of malfunction in mechanical and electrical maintenance or as an indicator of heat loss in buildings [7]. Historically, temperature has been proved to be a very good indicator of health where abnormal body temperature is a natural indicator of illness [8]. All objects with a temperature above absolute zero emit electromagnetic radiation, which is known as infrared (i.e., below red) radiation or thermal radiation [8], [9], [10]. The main purposes of finding IR transparent material in the band of human IR emitting range for medical thermal imaging are:

1. Finding a material that can pass IR in the human body range to be installed between the human body and thermal detector to avoid contamination of IR detector when using IR thermography to a lot of human subjects to detect the pandemic.
2. For weight bearing thermography when the doctor needs a thermal image to get a valuable information about foot, spinal cord, or vertebral column under body weight or additional external weight pressure.

There are two basic classifications of infrared optics:

Table 1: Some known Crystalline Infrared Optical Materials Chemical Formulas. For more details, please see references [11–14]:

	Chemical Formulas		**Chemical Formulas**
1.	$Al_{23}O_{27}N_5$	2.	MgO
3.	AIN	4.	MgO
5.	Al_2O_3	6.	$KAl_3Si_3O_{10}(OH)_2$
7.	Al_2O_3	8.	KBr
9.	$NH_4H_2PO_4$	10.	KC1
11.	BaF_2	12.	KH_2PO_4
13.	$BaTiO_3$	14.	KI
15.	BN	16.	RbBr
17.	BP	18.	RbCl
19.	CdF_2	20.	Rbl
21.	Cd_3P_2	22.	Se
23.	CdSe	24.	Si
25.	CdS	26.	SiC
27.	CdTe	28.	SiO_2
29.	$CaCO_3$	30.	Si_3N_4
31.	CaF_2	32.	AgBr
33.	$CaLa_2S_4$	34.	AgCl
35.	CsBr	36.	NaCl
37.	Csl	38.	NaF
39.	CuCl	40.	$SrBaNb_3O_6$
41.	C	42.	SrF_2
43.	GaSb	44.	$SrTiO_3$
45.	GaAs	46.	Te
47.	GaP	48.	TIBr
49.	GaSe	50.	Tl(Br,I)
51.	Ge	52.	TICl
53.	InSb	54.	TiO_2
55.	InAs	56.	Y_2O_3

57.	InP	58.	Y_2O_3
59.	LaF_3	60.	Y_2O_3-La
61.	PbF_2	62.	ZnCl2
63.	PbSe	64.	ZnSe
65.	PbS	66.	ZnSe
67.	PbTe	68.	ZnS
69.	LiF	70.	ZnS
71.	$LiNbO_3$	72.	ZnS
73.	$MgAl_2O_4$	74.	ZnS
75.	$MgAl_2O$	76.	ZrO_2
77.	MgF_2	78.	ZrO_2-Y_2O_3
79.	MgF_2		

Class IR optical materials, sample of these materials are shown in table 2.

Table 2: Glass Infrared Optical Materials Chemical Formulas, for more details about more than 24 materials we can restrict, please see the following references [11–16]

	Chemical Formulas		**Chemical Formulas**
1.	As_2S_3	**2.**	$Ge_{28}Sb_{12}Se_{60}$
3.	BeF_2	**4.**	Ge_{33} As_{12} Se_{55}
5.	Ge25 Se75		

1.2. Physical Background

Transparency, also known as pellucidity or diaphaneity, is the material physical property of allowing light to pass through it without significantly scattering. On a macroscopic scale, where the dimensions are much larger than the wavelengths of the photons, the photons obey Snell's law $\frac{\sin\theta_1}{\sin\theta_2}=\frac{n_2}{n_1}=\frac{v_1}{v_2}$ [17] where:

1. θ_1 and θ_2: angle of incidence and angle of refraction respectively.
2. n_1 and n_2 : refractive index of the first and second medium respectively.
3. v_1 and v_2 : phase velocities in the first and second medium respectively.

Translucency (also called translucence or translucidity) allows light to pass through but does not necessarily (again, on the macroscopic scale) obey Snell's law; the photons can be scattered at either of the material interfaces or internally according to the change in refraction index. In short, a transparent material is made up of components with a uniform index of refraction, while a translucent material is made up of components with different indices of refraction [18]. When an IR electromagnetic radiation of a given frequency Strick a material, the material will absorb the energy of the incident electromagnetic radiation and transform it into thermal energy of vibrational motion if its particles having the same or resonant vibrational frequencies of those particles. If the material has different atoms and molecules natural frequencies of vibration, they will selectively absorb a portion of the spectrum from the incident infrared light. Reflection and transmission of light waves occur because the frequencies of the IR electromagnetic radiation do not match the natural resonant frequencies of vibration of the objects. If the object is transparent for IR, then IR electromagnetic radiation are passed on to neighboring atoms through the bulk of the material and re-emitted on the opposite side of the object. Such frequencies of IR electromagnetic radiation are referred as transmitted [19].

2. Materials and Methods

An IR detector from sensor technology model (iHA417W) detecting range (8-14) micron, resolution 384×288, and 17µm pixel size have been used. A flame gas lighter and human subject 43 years old, 70Kg, 179cm length male used as an IR radiation source. Several materials have been used as barrier between the IR detector (IR detector) and the IR radiation from human source, and flame lighter as follows:

1. Fused Silica as shown in figure 1.
2. Thin sheet of Poly Vinyl Acetate (PVA) as shown in figure 2.
3. Transparent Plastic used in canon 3 in 1 scanner as shown in figure 3.
4. Sheet of silicon plastic (5 mm) that used in kitchen as shown in figure 4.
5. Tin material (3 mm) as shown in figure 5.
6. Shaded (8 mm) and unshaded (5 mm) glass as shown in figure 6.
7. Unshaded, half shaded, and shaded optical polycarbonate glasses lenses (all 0°) as shown in figures 7, 8, and 9 respectively.
8. Other materials such as wood, steel, Aluminum, and natural lather have been also used.
9. A thin sheet (35µm) of Graphene, Size: 10 cm x 10 cm, Thickness: 35 µm, Highly Conductive from Nanografi company as shown in figure 10.

At room temperature (24°C):
1. An IR Detector have been connected to the computer and the imaging mode activated.
2. The human subject and a fire lighter sated in front of the IR detector at a constant distance equal to 50cm.
3. An IR image taken for both human subject and lighter in sequence.
4. The barriers materials have been localized in series between the IR detector and the IR source (human subject) and lighter in sequence.
5. The resulted thermographic images were saved.
6. Graphene transparency percentage were calculated for both wide IR band from fire source and for narrow IR band from human source by measuring IR temperature for these sources with and without Graphene sheet as shown in figures 12 and 13.

3. Theory and Formula

Transparency $(\frac{I}{I_0})$ for IR electromagnetic radiation can be estimated from its thermal effect as shown in equations 1 (Stefan-Boltzmann Law) [20], 2 (Bouguer's Law) [21], and 3 below: as shown in equations 1, 2, and 3 below:

$$I = \frac{P}{A} = \varepsilon\sigma T_I^4 \quad ...(1)$$

$$\boldsymbol{I = I_0 e^{-\alpha X}} \quad ...(2)$$

From equations 1 and 2:

$$\frac{I}{I_0} = \frac{T_I^4}{T_{I_0}^4} \quad ...(3)$$

Where:

I_o: Intensity of incident or source electromagnetic radiation
I: Intensity of the passing electromagnetic radiation
ε: Emission
σ: Stefan Boltzmann constant, 1.380649×10^{-23} J/°K
T: Temperature in Kelvin where $T_K = T_C + 273.15$

Accordingly, this work test depends on direct detection of IR electromagnetic radiation from two kind of sources directly without any barrier between the source and the detector and compare it with indirect detection of the same IR electromagnetic radiation from the same kind of IR sources where the material wanted to be tested for transparency located between the thermal source and the detector. The result obtained from thermal detector to test prove transparency and by applying the above equations the value of transparency calculated

6. Results and Discussion

As shown in figures 1 to 10 above, results prove that:
1. Most of the tested materials (Fused Silica, PVA, Transparent Plastic, Shaded and unshaded glass, and Graphene) shows some transparency to IR emitted from gas lighter flame and IR image were detected by IR detector.
2. All the tested materials were opaque to the human subject IR radiations except Graphene which was transparent to IR radiations emitted from human subject as shown in figures 1-12 below:

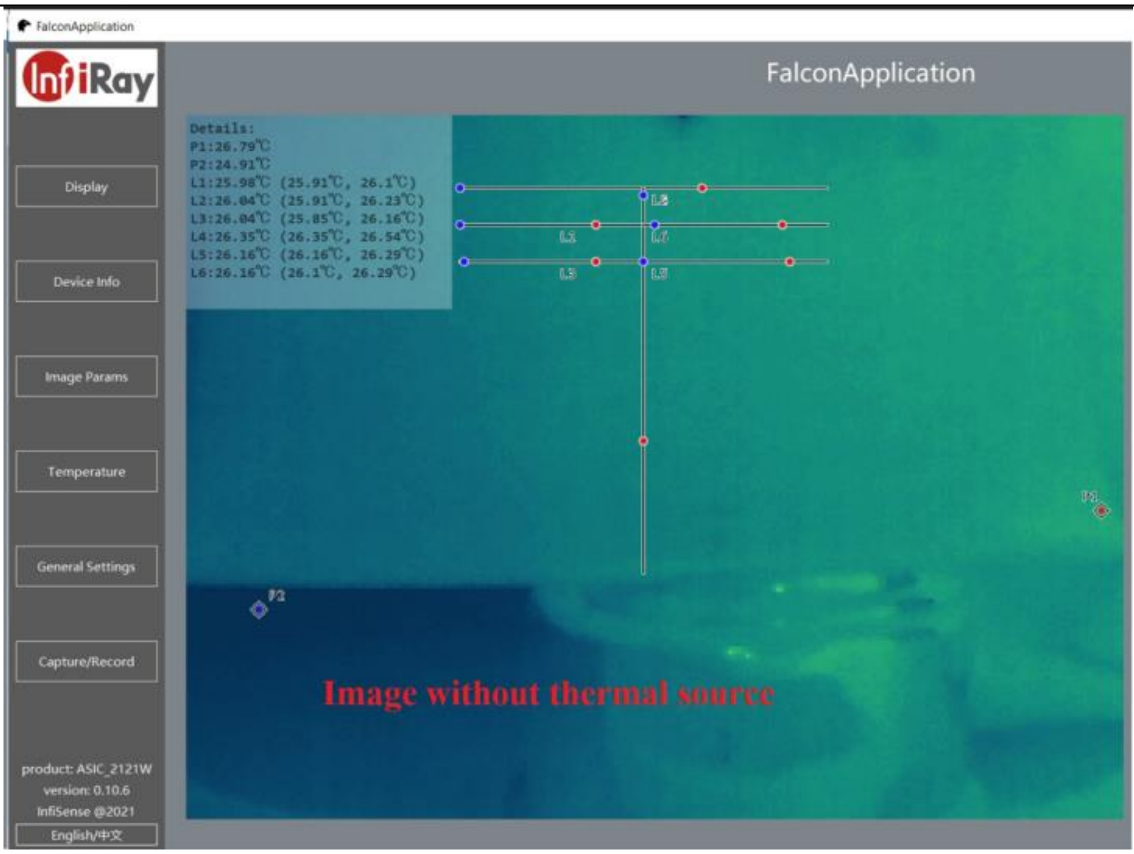

Figure 1. Shows temperature measurement average for now source as control max at L4 (26.35°C) as control

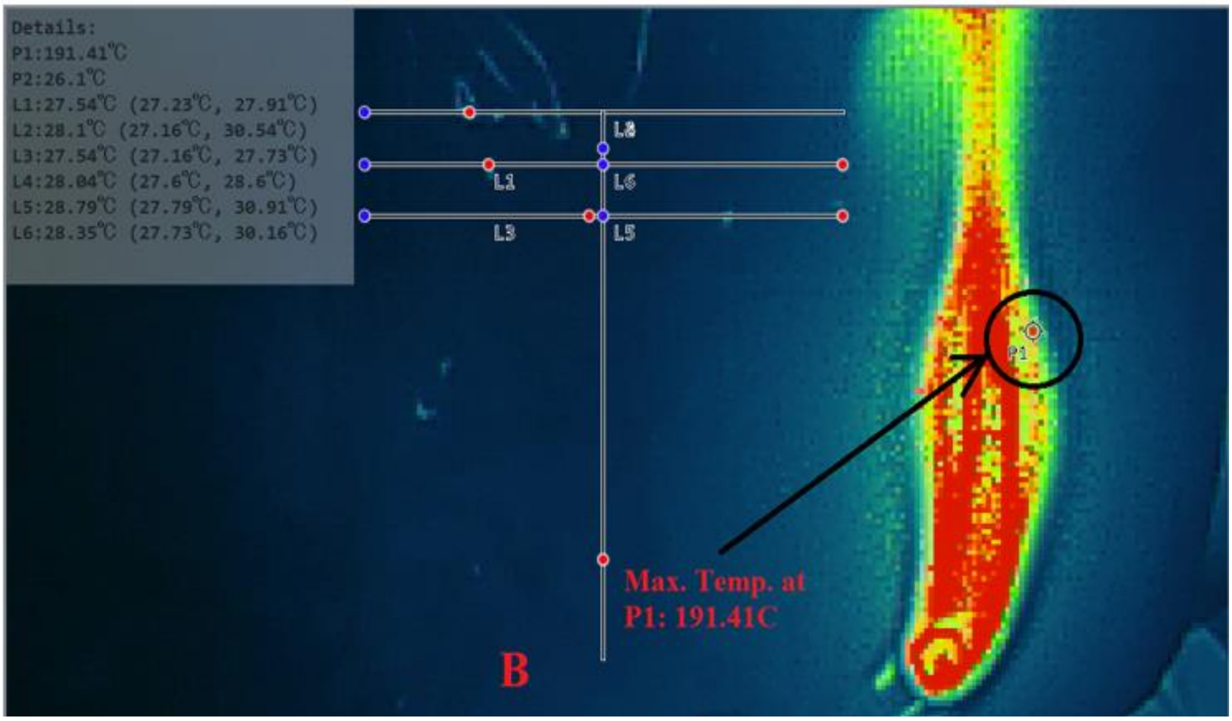

Figure 2. Shows temperature measurement average for gas lighter flame without any barrier max at P1

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(191°C) as control 2

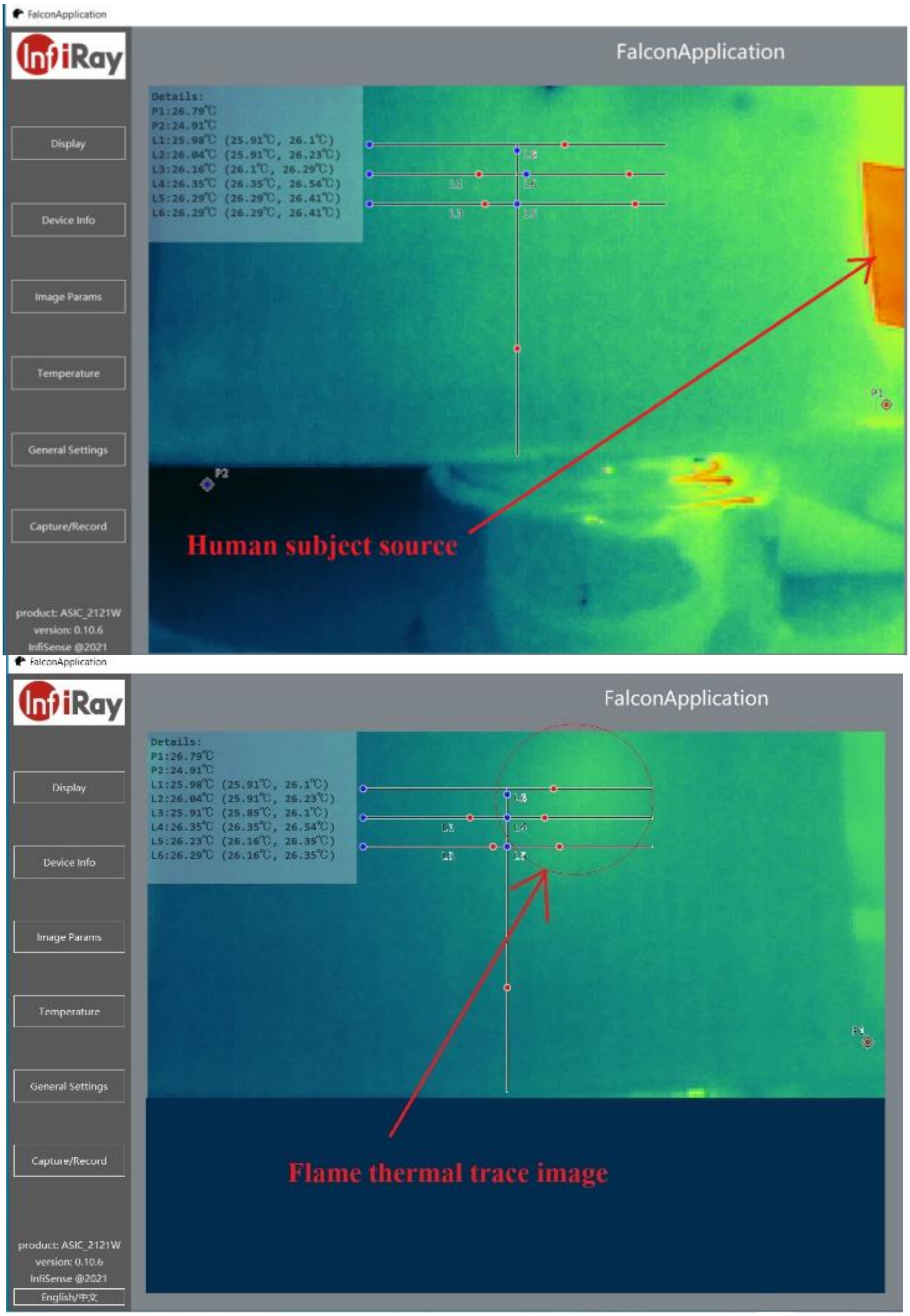

Figure 3. Shows IR transparency test for fused silica. (a) Shows temperature measurement average for human source max at L4 (26.35°C), (b) Shows temperature measurement average for gas lighter flame through fused silica max at L4 (26.39°C), comparing (a) and control 1 both (26.35°C) shows that human source

has no effect on temperature measurement so it is opaque behind the silica barrier. While comparing (b) 26.39°C with control 1shows a different of 0.05°C shows that there is some transparency for flam source but it is very low transparency compared to 191°C of direct measurement in control 2

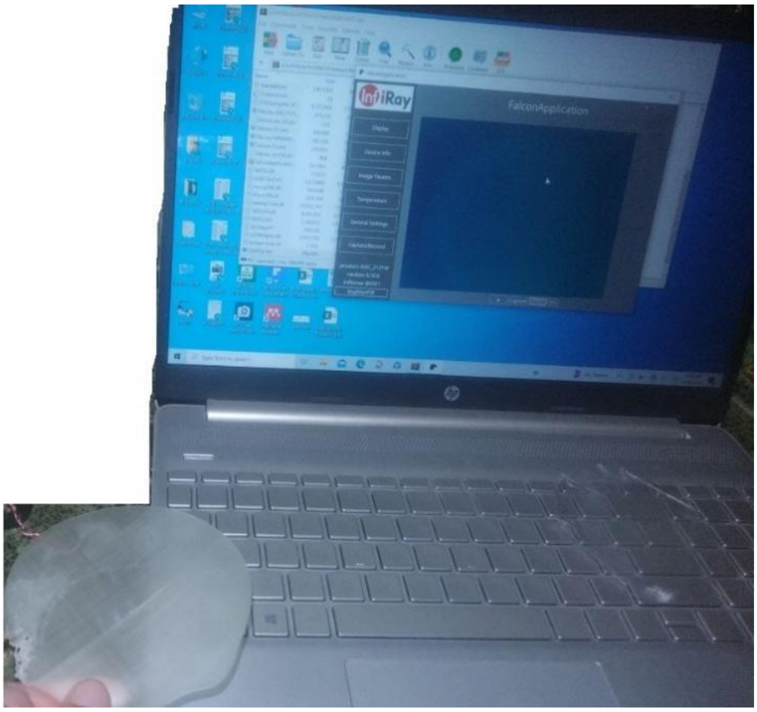

Figure 4. Shows IR transparency test for PVA

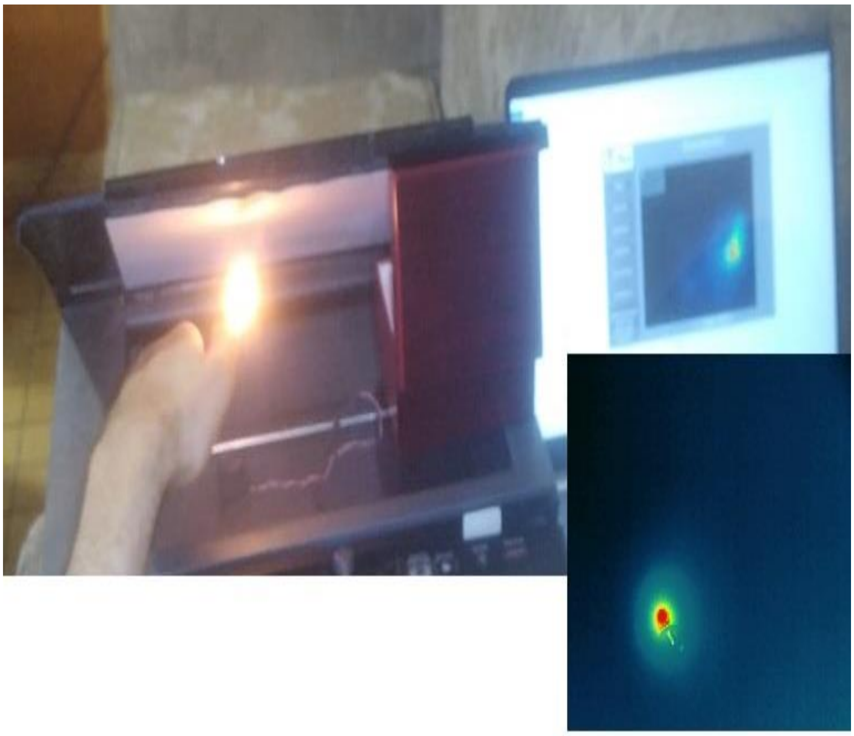

Figure 5. Shows IR transparency test for transparent plastic used in IR scanner

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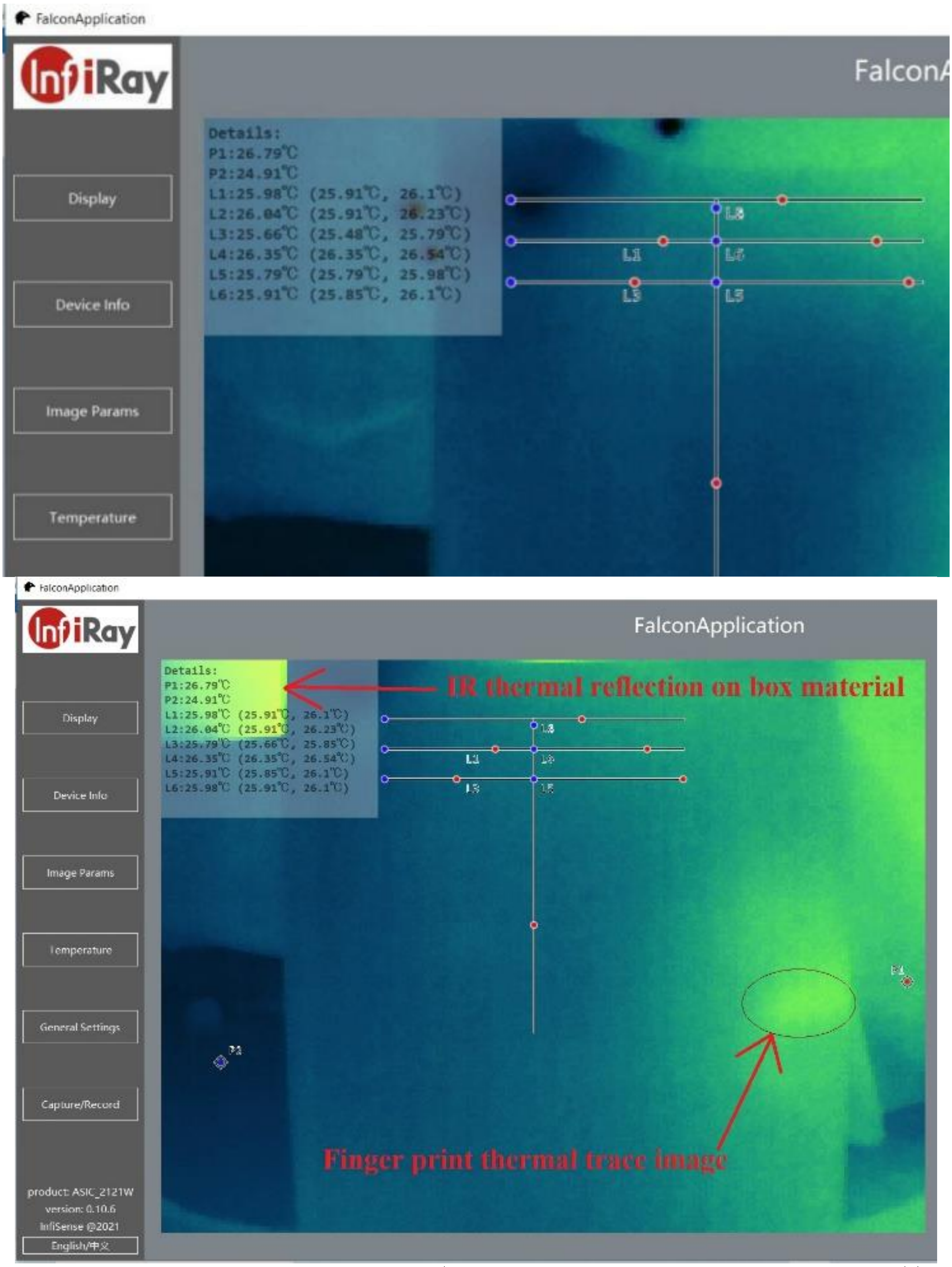

Figure 6. Shows IR transparency test for plastic (the image shows that IR detector capture the (a) Shows temperature measurement average for human source max at L4 (26.35°C) so it is opaque for human source as shown in control 1. (b) Shows temperature measurement average for gas lighter flame through plastic max at L4 (26.35°C), so it is opaque for gas lighter flame too.

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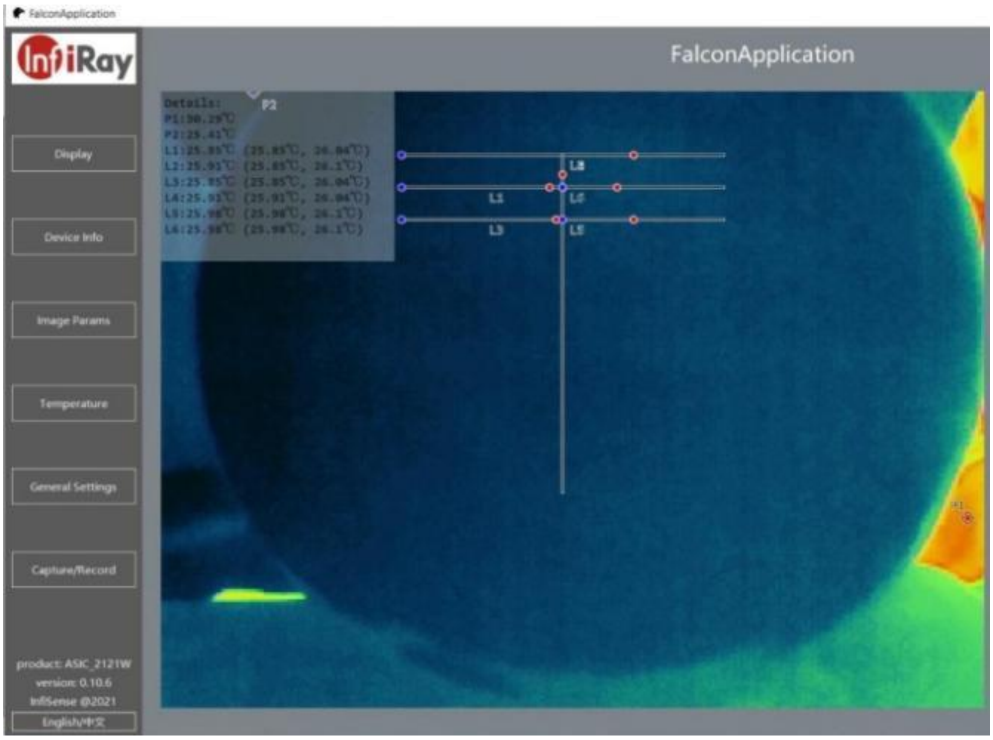
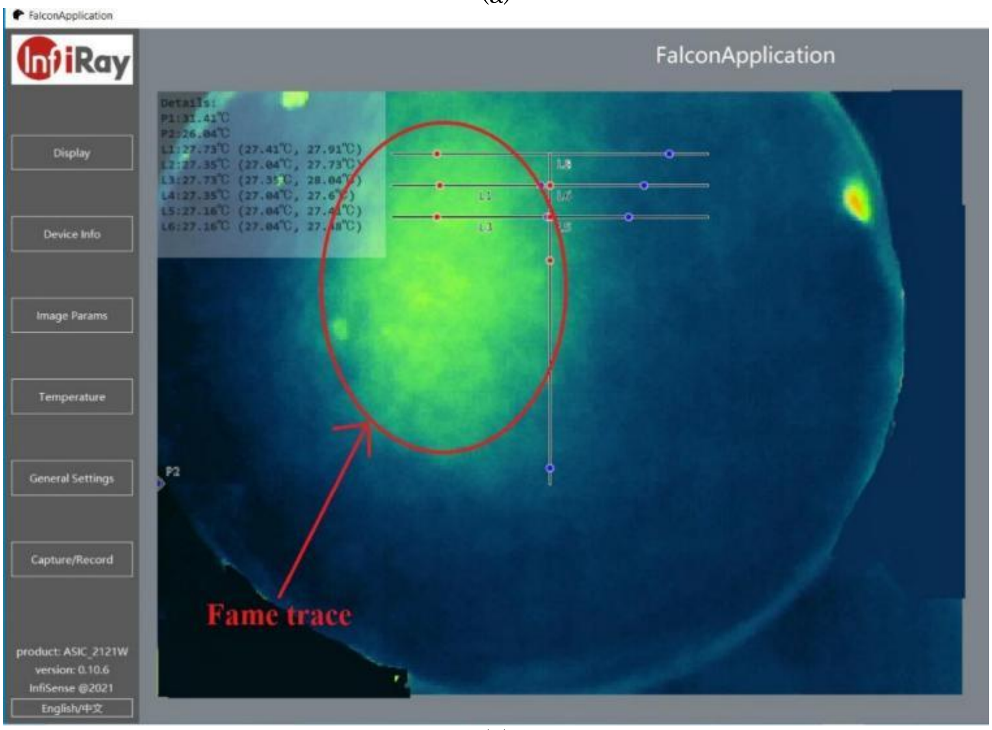


(a)



(b)

Figure 7. Shows IR transparency test for tin metal plat (the image shows that IR detector capture the flame IR radiation source behind the metal plate) (a) Shows temperature measurement average for human source max at L4 (26.35°C) so it is opaque for human source as shown in control 1. (b) Shows temperature measurement average for gas lighter flame through tin metal max at L3 (27.73°C). There is some

transparency for flam source but it is low transparency compared to 191°C of direct measurement in control 2 while the no source was L4 (26.35°C) so the passed IR is about 1.38°C compared to 191°C

Figure 8. Shows IR transparency test for unshaded glass

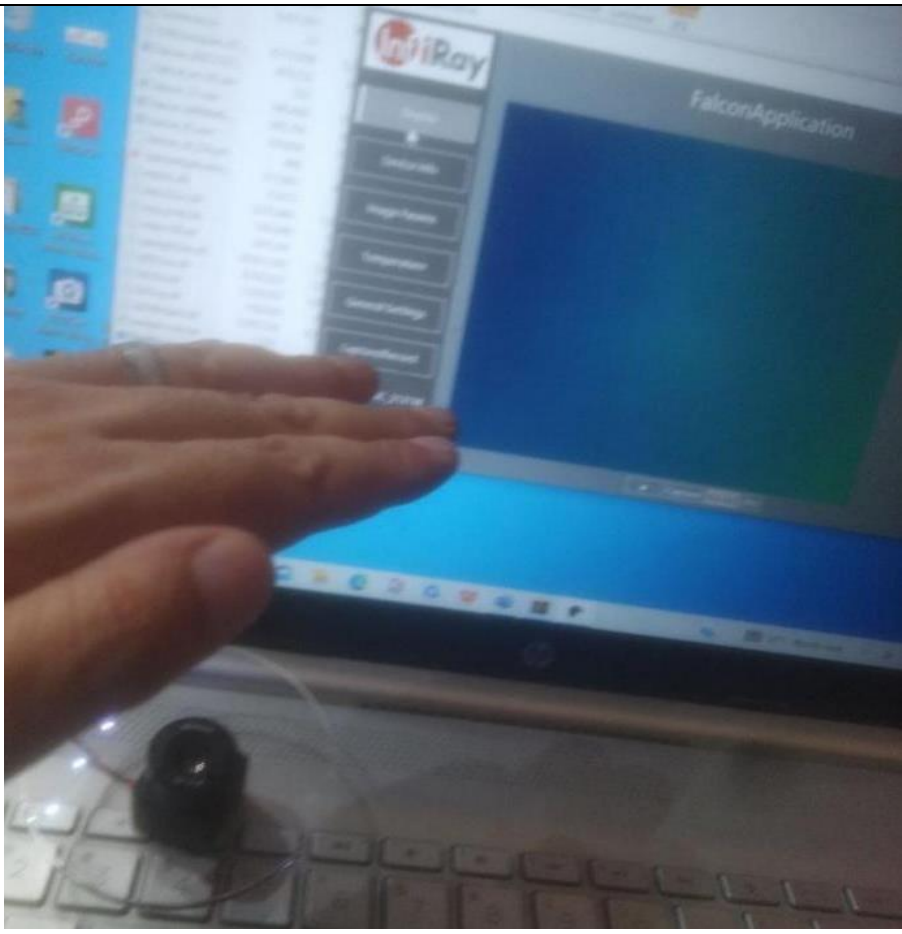


Figure 9. Unshaded Polycarbonate lenses

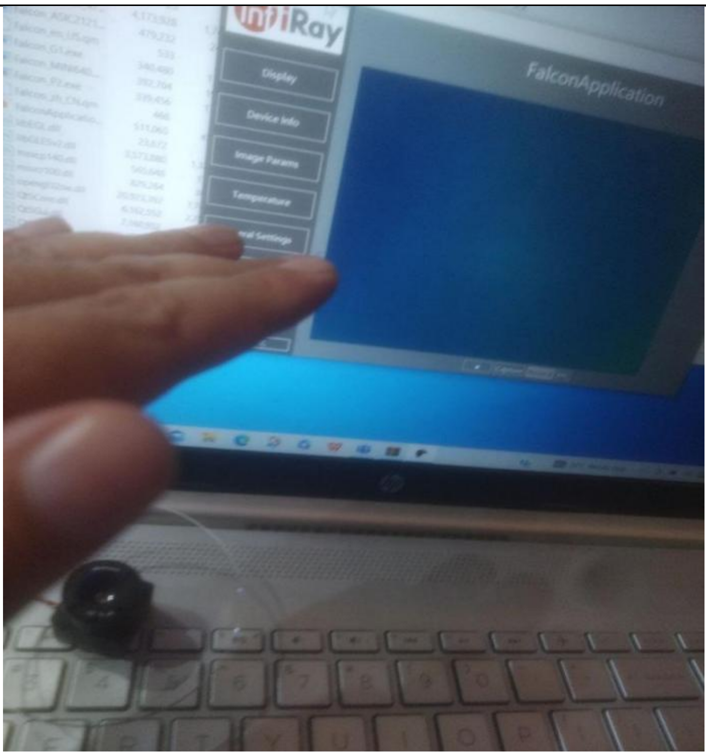


Figure 10. Half shaded Polycarbonate lenses

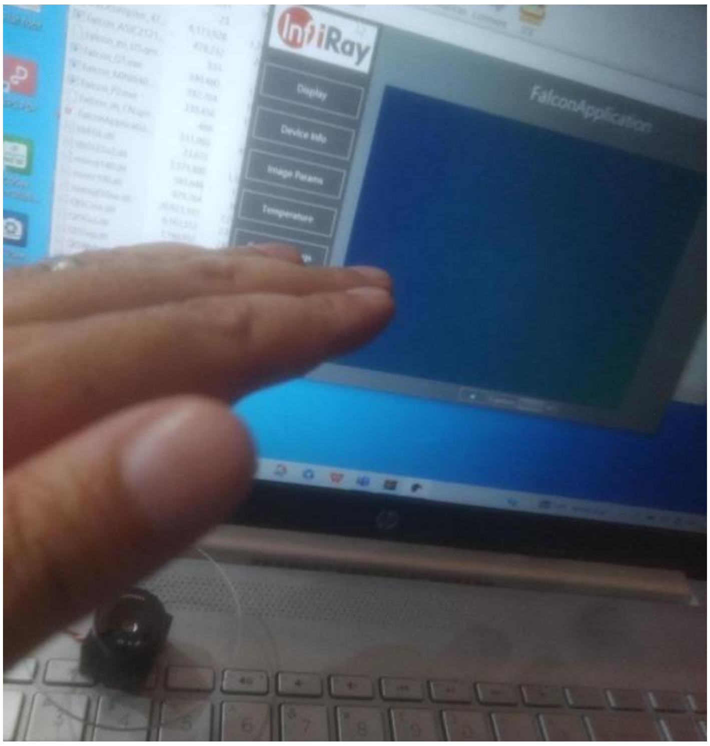


Figure 11. Shaded Polycarbonate lenses

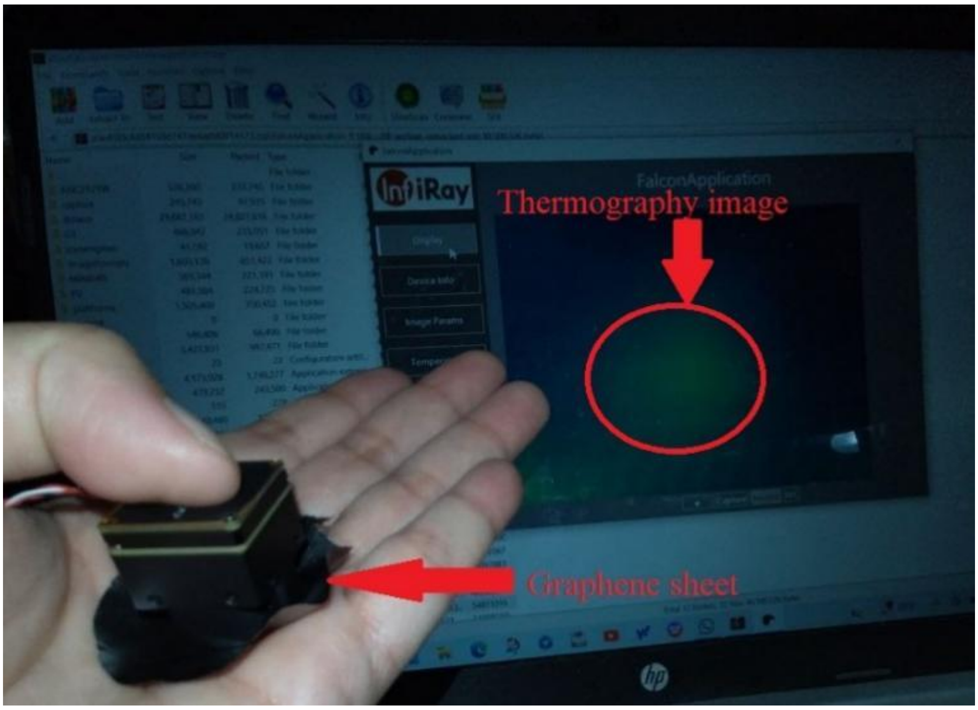


Figure 12. Shows IR image passes through Graphene sheet

3. Graphene transparency ($\frac{I}{I_O}$) for IR electromagnetic radiation at human source band, near IR band mostly at (8-14 μm) maximum intensity at 9.5μm is more than that emitted from gas lighter flame IR bands at the same band but maximum intensity at (8μm≅ 1250 cm^{-1}) [23] as shown in figures 13 and 14 below, by applying equations 1-3.

It was found that:

Case one: transparency of Graphene for human source IR bands:

$$\frac{I}{I_O} = \frac{(0.5+273.15)^4}{(29.35+273.15)^4} = 0.67$$

Case Two: Transparency of Graphene for fire source IR bands:

$$\frac{I}{I_O} = \frac{(6.44+273.15)^4}{(191.41+273.15)^4} = 0.13$$

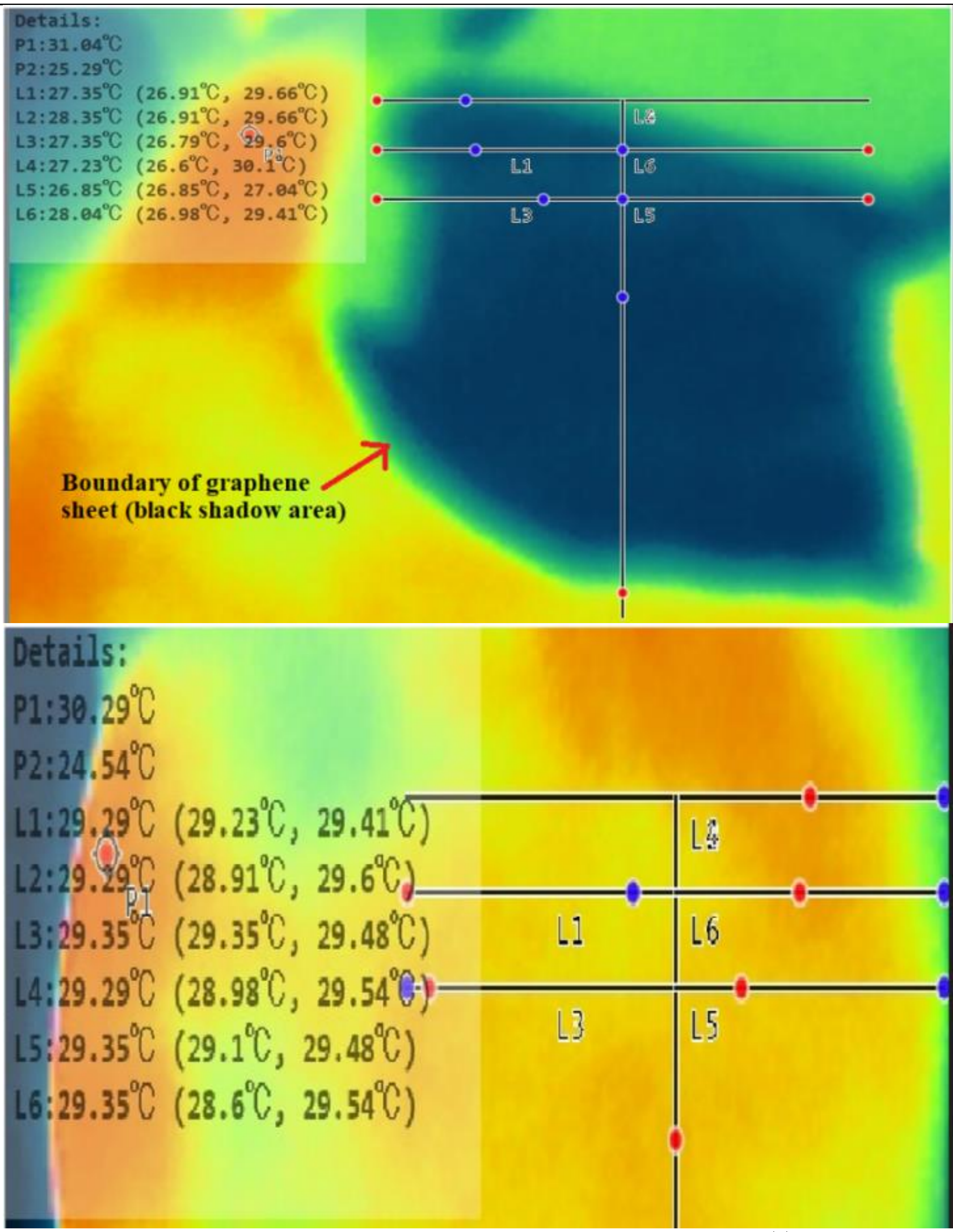


Figure 13. Graphene transparency measurement for IR electromagnetic radiation, (a) Shows thermographic image of human source with Graphene sheet partition (L5 all located inside Graphene area, average temperature is 26.85 C) i.e net of 0.9°C comparing with control 1, (b) Shows thermographic image of human source without Graphene sheet partition (L5 all located inside Graphene area, average temperature is 29.35 C) i.e., net of 6.44 comparing with control1.

Note: both images captured from approximately the same distance and under the same conditions.

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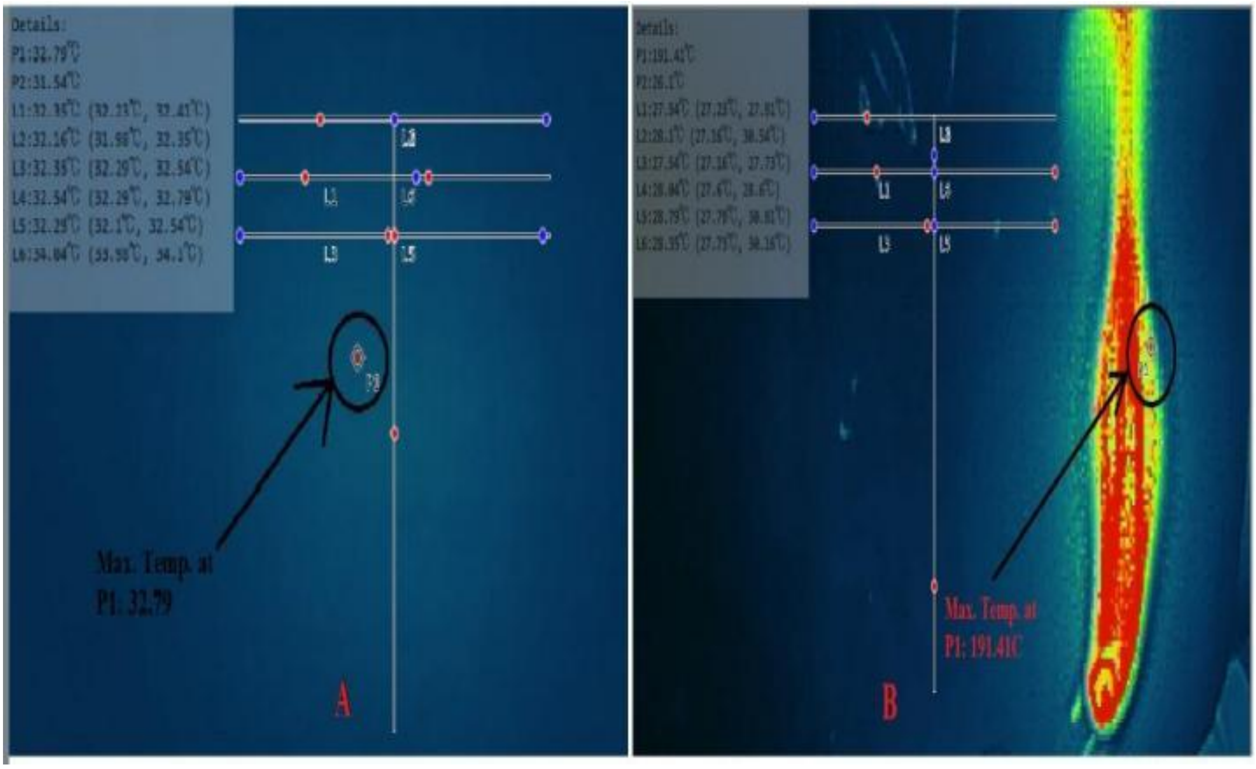

Figure 14. Graphene transparency measurement for IR electromagnetic radiation, A: Thermographic image of gas lighter flame source with Graphene sheet partition (P1 represent the maximum temperature located inside Graphene area, 32.79 C), B: Thermographic image of fire lighter source without Graphene sheet partition (P1 represent the maximum temperature located inside the same zone of Graphene area, 191.41°C). Note: both images captured from approximately the same distance and under the same conditions.

4. Transparency for other tested materials to IR bands emitted from human body were Zero according to the IR detector measurements used in this study.

Transparency of other materials for gas lighter flame source IR bands can be interested for comparison. Some of tested material transparency shown in table below:

Table 3. Transparency of Materials.

No.	Material	Transparency to IR %
1.	Fused Silica	0.120
2.	Tin metal	0.122

As known, all living subjects that have temperature above zero absolute emit IR radiation [2]. In this study a practical test uses several IR transparent materials used but most of them were practically tested for IR transparency. Only Graphene sheet which is one layer of Carbon (35µm) was transparent to human IR radiation. This is related to several factors such as:

1. Low emissivity of human body radiation so it was an able to pass through the barriers used from the tested materials and reach IR detector without beaning absorbed or distracted.
2. There are two peaks for spectral IR intensity emitted from human source at 9.5µm and 12µm while the peak from IR gas flame is at 8µm=1250 wavenumber [22]. In spite of fire thermal radiation is much larger in its temperature than human source, Gas flame: 191.14°C > Human source 28.9°C. It was noticed that Graphene shows higher

transparency to IR from human source than that from gas flame for the same band (8-14μm) which IR detector band. This can be because of that Graphene act as a stop band filter for peak wavelength intensity of the flame at 8μm and as a pass band filter for the peak wavelengths of human source IR emissions at both 9.5μm and/or 12μm. For specifying that exactly, more investigations is required using a wavelength controllable IR radiation source and test each wavelength from 8μm to 14μm. This will be additional use for this material (Graphene).

3. Thermal image of human source through graphene shows poor thermal pattern of functional anatomy of human source, according to that graphene can be suitable to protect thermal detectors in medical applications required only temperature measurement but not suitable for application that requires functional anatomy.
4. The distance from detector to source and placement of sample material between them was constant in this study. The material localized directly in front of the detector and the source located about 50cm away to protect sample material from born by gas flame.
5. Transparency of material depend on the thickness of that material. This property of sample material was not calculated in this study because it is out of the aim of this study.
6. This study transparency calculation depends on the temperature difference recorded by the detector from the surface of the tested materials (graphene, tin metals, and fused silica) when there is a thermal source behind the material and when there is not (i.e., I in equation 3 was calculated for graphene as an example: $T_1 = 26.85 - 26.35 = 0.5°C$). That is because this study was not accomplished at an absolute zero temperature. Although the total recorded temperature depends on the calculation, the result will be 0.96. The change is not very large because the difference between the second value to change to kelvin in the equation (273.15) is more than ten times the temperature. To calculate the transparency using IR detector thermal measurement directly, a special environment of absolute zero degree is required to do the experiment, which is out of the facility of this study.
7. It must also be known that the effect of the distance between the detector and the radiation source on all results was not significant in this study because the detector had limitations on two modes of measuring distance: 50 cm and 5 m. Accordingly, this study measurement was limited to a 50 cm distance, and this practical shows no differences greater than 0.05 °C. Using the other mode (5 m), need a special opaque lab of more than 5 m length, which was not available for this study. For more details about detector specifications, please visit the product page on the web (https://www.gst-ir.net/uploads/products/pdf/iha417w-thermal-module.pdf)

7. Conclusions

There are a lot of IR transparent materials but as shown in the tables mentioned above in introduction section. For IR radiation bands emitted from human body most of these materials were practically opaque because of low emissivity of human IR radiation source which is about (emissivity of ~0.98) [3], [24]. Finally, this study found that Graphene is a promising IR transparent material. As a future work, thermal trace of finger prints on some tested material shown in tested figures above could be investigated to find-out if it is due to heat transfer or pressure heat.

Acknowledgments:

My sincere gratitude goes out to everyone who assisted me in finishing this study: the esteemed professor Athir Al-Obaidi of the Laser Institute for Postgraduate Studies, University of Baghdad, for his guidance; Dr. Aseel Mohammed, a lecturer at Al-Nahrain University, Department of Biomedical Engineering, for providing the EVA material; and the editors of Al-Nahrain Journal, particularly Professors Dr. Farah Aqeel and Ahmed Al-Tabbakh, for their support and guidance.

Funding:

We, as authors, would like to clarify that this research did not receive any funding from any party.

Conflict of Interest:

There is no conflict of interest regarding this work.

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