A Perspective on Wavelength Transformation by Absorptive Optical Filters

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(Updated 12/21/18) There has been much discussion within the fluorescent mineral community recently about the functioning of absorptive filters when used in conjunction with UV LEDs. Much of this dialogue has been centered around USP 7,781,751 by Gardner (2010). While perhaps the ultimate embodiment of this patent would be a flashlight containing high power UVC-emitting LEDs and providing for the selective use of phosphor-loaded UV transparent film filters, the language of the patent anticipates multiple embodiments. In the *Detailed Description of the Invention* of the cited patent, lines 41-45 read:

> *"The (wavelength transforming) materials…of any preferred embodiments may comprise any material or system that absorbs light of one wavelength or band of wavelengths and emits light of another wavelength or band of wavelengths, thus modifying the distribution of spectral density."*

"Wavelength transforming" is therefore an interesting aspect to consider. Presented here is a perspective for the reader's consideration.

The Nature of This Article

This article provides a simple physics demonstration that can be used to explore terms such as "wavelength distribution" and "wavelength transforming" as they may apply to absorptive filters such as common longwave UV filters (such as Kokomo and Wood's Glass) or shortwave filters (such as Hoya U-325C). This demonstration can be reproduced by anyone with basic equipment – a "well equipped basement". And this is only a *demonstration*, as it does not reveal any physical principle not already known to someone familiar with the basics of light interaction with matter. It is completely qualitative, as performing a definitive, quantitative characterization would require the use of a high intensity UV source in conjunction with specialized instrumentation, including spectrophotometric equipment that could function over the wavelength range of ~250-13000 nm. Only then could the light source and transmission characteristics – as well as emissivity considerations – of all filter materials be well characterized. Though necessarily including well-known physical principles, this is not a technical paper *per se*.

In the case of subtractive filters such as those specifically mentioned, there is a relatively high percentage of absorption of unwanted visible wavelengths and reasonably high transmission of the desired UV band(s) – the intentional result of carefully formulated glass chemistry. Concurrent with the production of this desired wavelength transmission, through whatever set of physical mechanisms, it is recognized that absorbed optical energy ends up being converted into heat. While this effect is not always apparent due to the more aggressive heating of UV filter glass by nearby heat sources (such as a Hg vapor discharge tube), it is nevertheless present as a small component of the overall filter heating. Conservation of energy dictates that the absorbed optical energy cannot simply vanish. This demonstration illustrates a method whereby this effect can be examined in a simple, qualitative manner by anyone interested in doing so. Results would be expected to vary somewhat based on the specific combination of equipment and filter media used.

What This Article Is Not

It is not the purpose of the author to take sides in the current debate over the validity or applicability of any patent to any commercial UV-generating device, but rather to describe readily observable effects that may be viewed as relevant to the terminology being discussed within the fluorescent mineral community. The nature of this article is informational. It deals with basic science observations and does not address any aspect of patent law whatsoever – nor should any be inferred by the reader. This article makes no statement of what must be concluded, but rather presents a means of observing filter response resulting from the absorption of energy from a light source.

The Demonstration

If what is said in the 3rd paragraph about absorptive filters is correct, then one would expect to see a manifestation of filter heating induced by absorption of optical energy if a suitably sensitive method of detection was available. Modern thermal imagers provide a convenient way to sense local low level heating. But before proceeding further, a brief review of IR wavelengths is valuable. There are several schemes for IR band definition and Table 1 presents only one. Atmospheric gas species absorb strongly in defined IR wavelength intervals – an inescapable filtration process in open air that produces absorption bands that in turn have been used to define the IR transmission bands.

Table 1. IR bands resulting from atmospheric transmission.

Names	Wavelength Interval (μm)	Common sources
Near IR (NIR)	0.7 – 1.4	Incandescent light sources, sun, IR LEDs, lasers, night sky.
Shortwave (SWIR)	1.4 – 3	Incandescent sources, sun, IR LEDs, lasers.
Midwave (MWIR)	3 – 5	Incandescent sources, sun, IR LEDs, lasers, combustion.
Longwave (LWIR)	8 - 13	Sun, lasers, thermal radiation from warm objects and living organisms

In order to look for a subtle heat signature resulting from incident beam energy absorption in a filter, one must be able to selectively sense LWIR. Commonly available thermal imagers look only at LWIR emitted from “hot” objects, with “hot” being displayed relative to the other objects sensed in a given field of view. Thus, a given display shows what is "relatively hot”. The selective sensitivity of thermal viewers allow them to be used in broad daylight and brightly lit rooms with no optical interference. The unit used for this demonstration was manufactured by FLIR, and was designed for imaging at much greater distances than used in this demonstration. This fact contributed to low-res, out-of-focus images though thermal images from affordable units are never extremely sharp. The FLIR manual listed the sensor as a vanadium oxide microbolometer. An iPhone 6 was used to capture the ~2X images appearing on the thermal viewer screen.

The author’s previous experiences with thermal imaging created an awareness that ordinary window glass (soda lime) effectively blocks LWIR. This can be shown in the following manner. Figure 1 shows the thermal image of a coffee cup filled with hot water. A glass plate can be positioned as shown in Figure 2.A to block approximately half of the coffee cup, giving rise to the LWIR image in Figure 2.B. In that latter image, the glass plate effectively blocked the thermal emission of the hot cup. While effective in blocking incident LWIR, when heated, the soda lime glass can also become an effective emitter of a LWIR heat signature as shown in Figure 3. Here, a thermal hand print made on the glass plate persisted for a number of seconds after contact. It was discovered early in setting up this demonstration that stray heat signatures were appearing on objects. This was quickly attributed to heating of components simply by handling. Not visible in any of the pictures was a small fan used to gently cool the components to minimize any such thermal artifacts.

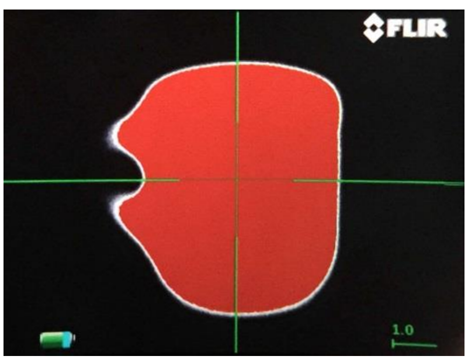

Figure 1. LWIR image of coffee cup filled with hot water.

Figure 2.A. White light view of soda lime. glass plate blocking ~1/2 of coffee cup.

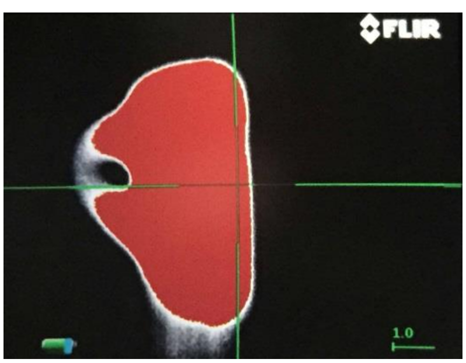

Figure 2.B. Thermal image showing the blocking effect of soda lime glass.

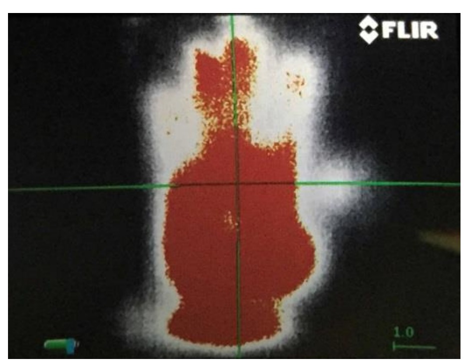

Figure 3. Thermal signature of hand print on glass LWIR plate in LWIR.

That optical response of soda lime glass was useful in constructing the demonstration that will be described. The basic elements of the demonstration are illustrated by the diagram comprising Figure 4. A common white light LED flashlight was selected as a convenient source of intense, relatively collimated light. Filtering of white light is the primary function of most UV filters. This unit emitted ~500 lumens. Consulting the Cree XM-L2 datasheet for the 5000K version, it was found that the diode emits slight NIR, but IR production falls to ~0% by 780 nm. There was no UV production indicated. Though not listed on the Cree datasheet, there would have to be LWIR radiating from the flashlight given heat dissipated by the LED. Next in the beam path of this layout was a 1.5" OD thin walled aluminum tube used as a collimator to limit stray light from the flashlight.

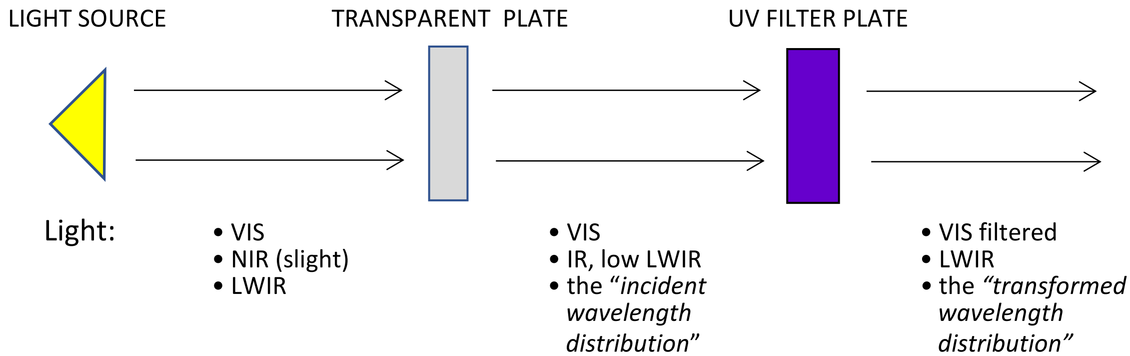

Figure 4. The arrangement of chosen components for the demonstration was based on limitations of using simple equipment. Terms for the incident and transmitted spectra resembling the language of the cited patent are used to convey their location relative to the component layout.

The defined beam then passed through a transparent soda-lime glass plate obtained from a picture frame. Consulting several internet sites revealed that the transmission spectrum of high silica glasses (including both soda lime as well as borosilicate) have an IR cutoff of ~4.5 µm. (Other specialty silicate glasses such as Schott KG-5 used as heat absorbing filters have a glass chemistry engineered to result in a more rapid IR cutoff of ~0.9 µm.) The glass plate served to block most LWIR from the light source. The "transparent" glass plate however was not truly transparent, though clear to the eye. Any absorbed wavelengths would be expected to give rise to local heating of the irradiated area. In the case of this soda lime plate, it would be expected that any resultant heat signature would be small given its relative transparency.

Light passing through the clear glass plate impinges on the front surface of the UV filter plate. For the demonstration, a broken plate of 3/16" thick Kokomo glass was employed simply because a loose piece was available. The high optical absorption of this filter should result in greater local heating if the incident spectrum is transformed by conversion of the absorbed portion of beam energy into heat – as would be evidenced by localized LWIR emission in the resultant spectral distribution on the back side of the filter. As the amount of LWIR in the incident spectrum falling on the UV filter must have been small due to the blocking effect of the soda lime glass, any higher LWIR emission imaged on the rear for the UV filter plate would provide evidence of conversion of incident light energy to heat.

The component layout corresponding to Figure 4 is seen in Figure 5.A in room light. In order to clearly see the position of a beam spot on the back of each glass plate in the thermal viewer image, small resistors were positioned to the right of each spot position, their value being chosen to each produce ~1/3W of ohmic heating when connected to 120V. In effect, the resistors when energized were "incandescing" in LWIR, providing dependable locators for any nearby LWIR emission spot that would constitute a demonstration of a new wavelength distribution not present in the incident wavelength distribution. Figure 5.B shows provides a thermal viewer image of this layout in operation.

Figure 5.B clearly shows the position of the two warm resistors – indicating the position of the clear glass and UV filter plates in the beam path. More importantly, this thermal image also shows a noticeable LWIR signature on the rear of the UV filter whereas there was none visible on the rear of the clear glass plate which evidently absorbed only very little of its incident radiation as expected. Absorbed optical energy caused local heating of the UV filter with a resultant emission of LWIR. The absorptive UV filter was seen to generate a new spectral distribution containing wavelengths not present to any detectable extent (with equipment used) in the incident spectrum. Figure 6 provides a complementary view of the glass plate and UV filter from a vertical perspective. The basic equipment used in this demonstration provided no capability to view NIR through MWIR wavelengths should they have been present – something a more detailed spectrophotometric

based approach could have provided. Differences in “hot spot” appearances between Figures 5.B and 6.B are attributable to the display adjustment behavior of the thermal imager for a given field as referenced earlier.

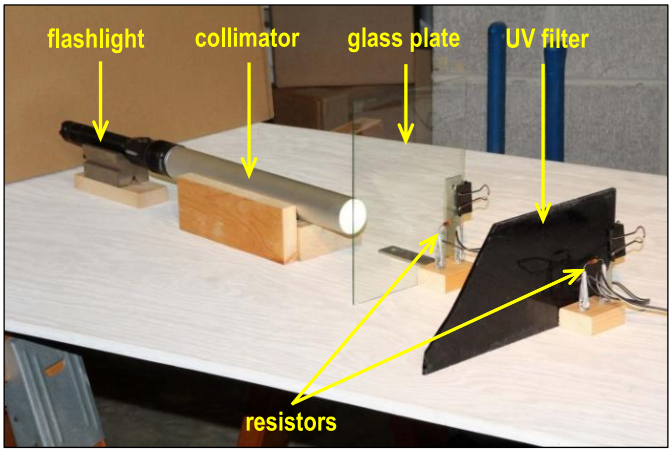

Figure 5.A. Horizontal view of components in white light. Key components are labeled.

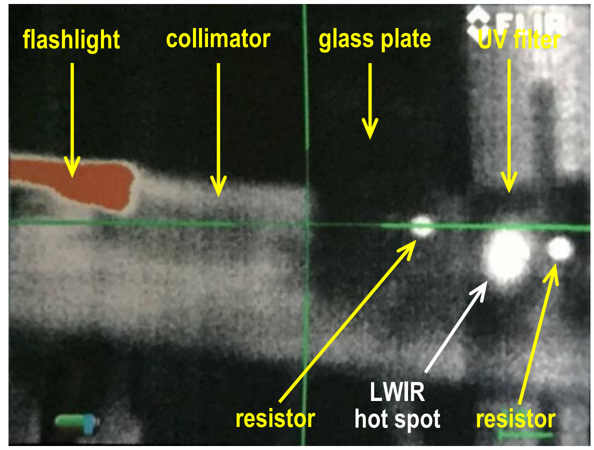

Figure 5.B. Horizontal view as seen in the thermal viewer. The hottest object in field of view was the flashlight body after minutes of runtime.

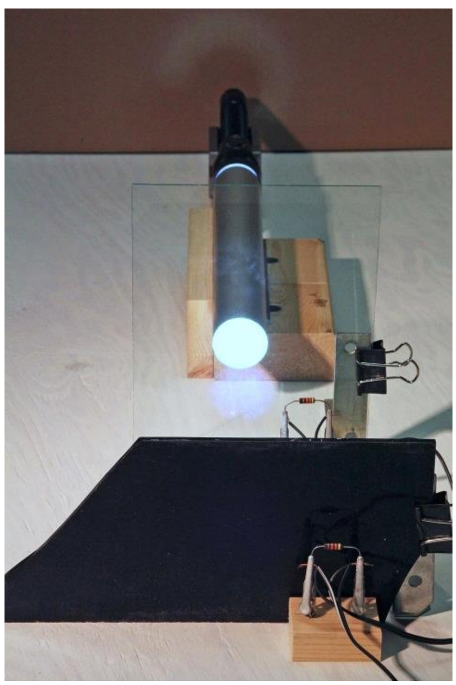

Figure 6.A. Vertical white light view of component layout. Note the resistor locations.

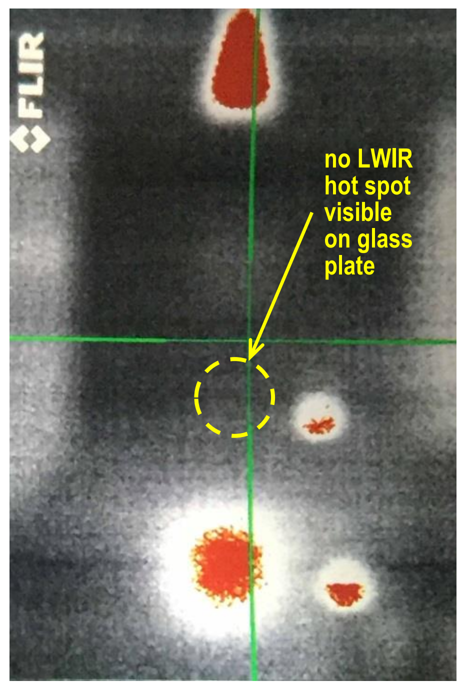

Figure 6.B. Strong thermal signatures were obtained from flashlight, the two resistors, and the rear of the UV filter.

It is tempting to think absorptive filters such as Kokomo Glass, Hoya U-325C, or other deep color filters are purely subtractive – simply eliminating unwanted wavelengths. However, this simple demonstration provided evidence that such filters create new wavelengths of light from the energy absorbed. The following generalized relationship for the absorptive filter functioning can be proposed based on the principle of conservation of energy:

incident optical energy (to the filter face)	=	reflected light energy (from the filter face)	+	transmitted light energy (from back of filter)	+	heat (internal)

The absorbed energy in the UV filter ultimately stimulates increased atomic motion, which manifests itself as heat. (This article does not address the detail of these mechanisms, as it is not a technical paper. Such questions should be deferred to an expert in this specific subject area.) The heat is then transferred from the generation volume by the 3 well known modes – conduction, convection, and radiation. For this particular scenario, none would have been particularly efficient – being limited by low filter thermal conductivity, small ΔT to ambient, and low T given T^4 dependence for radiative transfer, respectively. Localized heating in the irradiated volume of the absorptive filter, though subtle, was demonstrated to give rise to localized LWIR emission. Even after minutes of run time, there was only a LWIR signature seen from the beam spot on the back of the UV filter plate with no suggestion of any significant heat transfer by conduction (spreading) having taken place. This observation was again limited however by the nature of the equipment used. Convection could not have been effectively observed due to the gentle air movement induced by the nearby small fan.

Had a deep red or deep green filter (such as a heavy shade of welding filter glass) been used for this demonstration rather than a UV filter, one would expect a similar outcome (i.e., a LWIR "hot" spot visible on the back of filter). It can be expected that any absorptive filter – whether colored or neutral density – will exhibit this behavior. The extent of heating would be influenced by its optical density for a given incident wavelength distribution. It can be reasoned that only perfect transparency would eliminate such heating. Studies of such effects in relatively transparent materials would take equipment far more sophisticated than employed here.

The observations from this simple, qualitative physics demonstration appear consistent with the concept of a wavelength transformation. The images obtained in this demonstration showed that the generation of a significantly higher emission of LWIR occurred from a dense, absorptive optical filter in contrast to an optically "clear" medium in which far less conversion to heat was seen to occur. While such a conversion is not the primary intention of an absorptive UV filter and while the heating of the filter is neither useful (for mineral fluorescence applications) nor even desirable, heating nevertheless occurs as an inescapable result of absorption of incident beam energy.

Conclusion

This article offers the reader no conclusion. The purpose of this article is informational as initially stated – providing a simple means by which the action of highly absorptive filters can be explored with simple equipment. Interested readers are encouraged to perform their own tests, consider all the information they deem relevant to the topic, and come to their own perspective.