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TECHNICAL PAPER

COATING MATERIALS & TECHNOLOGY FOR LONG RANGE IR COATINGS

Growth in Applications

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Materion Coating Materials News

There are new developments in infrared (IR) materials and an ever growing number of applications for IR coatings. As a leading supplier, Materion specifically prepares and refines infrared (IR) coating materials to meet these increasing demands. Following is a review of the materials, technology and some of the applications that require IR coatings.

Applications of IR

The majority of IR applications operate at mid-wave and long-wave spectral regions where thermal energy exceeds the visible solar energy background (See Figure 1). The instruments and sensors for these regions detect emitted rather than reflected energy. There is a growing list of applications for IR instruments which is expected to expand as more and different IR sensors are developed and brought to market. Materials that are used in making thin-film coatings for these applications are also under continuous development. Among the applications are:

- Military and commercial intrusion detection for security: detection of heat sources such as vehicles and personnel under nighttime and camouflaged conditions.
- Invisible communications, night or daytime.
- Fire and rescue searching under smoke and nighttime restrictions.
- Biomedical thermography: detecting and monitoring tumor and circulation problems. Non-invasive and radiation-less imaging of breast cancer and circulatory blockage.
- Industrial and commercial: process temperature monitoring and the detection of heat loss points from buildings.
- Climate monitoring: determining distribution and concentration of atmospheric gases including water vapor, and ocean and land temperature mapping via satellite.
- Remote mineralogy: composition of planetary surfaces.
- Automobile night vision: detection and avoidance systems.

Basics of IR Technology

Previous issues of *Coating Materials News* have discussed IR technology [References 1, 2] if you wish to know more on the topic. The spectral regions of infrared energy that reach the surface of the earth are chopped up by water and carbon dioxide absorption bands in the atmosphere, leaving specific windows through which terrestrial IR instruments can operate (Figure 1). The full solar emission spectrum is only available in the extraterrestrial space environment.

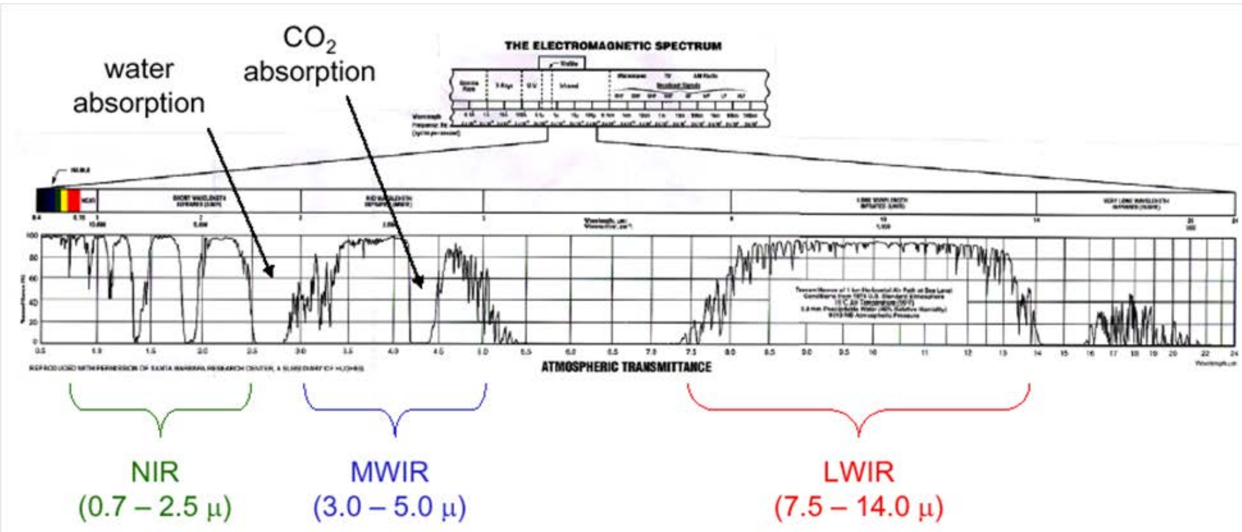

Figure 1. Indicated are: Solar energy vs wavelength that penetrates earth's atmosphere and the designations of IR regions. Energy of these wavelengths is invisible and requires special sensors and coatings for detection and imaging.

Expansion of the commercial market is already evident with the availability of IR imagers for fire and rescue personnel, and the installation of IR imagers on automobiles. IPads and phone cameras also introduce an IR capability. These popular applications were made possible by the economical development of wafer-level production capability of micro-bolometers for the 8 to 12 µm region. This type of sensor array does not require cooling below ambient temperature, thus overcoming the last barrier to the wide-spread application of IR imaging capability. Some IR sensor arrays require much greater sensitivity for applications in astronomy and for the detection of low concentrations of gases related to climate monitoring. These arrays are made from crystalline semiconductors and must be cooled to cryo-temperatures such as provided by liquid nitrogen.

Figure 2 shows the blackbody radiation emitted at different source temperatures. IR sensors coupled with their spectral filter and mirror coatings are designed to detect specific sources required for a particular application. For example, human thermography instruments sense radiation emitted from our body at ~300 K. Small temperature differences that may be due to localized abnormal vascular blood flow, as in the case with tumors or constricted blood vessels, can provide a more accurate diagnosis while avoiding exposure to harmful radiation.

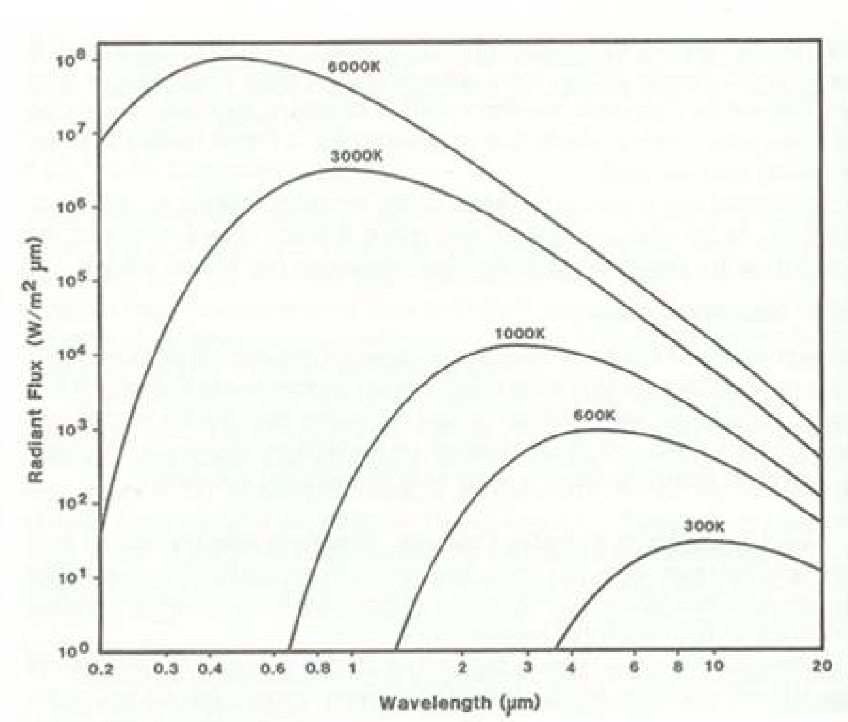

Figure 2. Emission from radiating bodies at different effective color temperatures.

Body temperature is slightly cooler than 300 K, so thermal imaging in the 8 to 12µm wavelengths is useful for medical and security applications. Solar color temperature is near 6000 K to give us visible light. Tungsten lamps with color temperature near 3000 K emit more near-IR energy than visible light.

Examples of thermography applied to global monitoring and medical diagnosis are shown in Figures 3 and Figure 4.

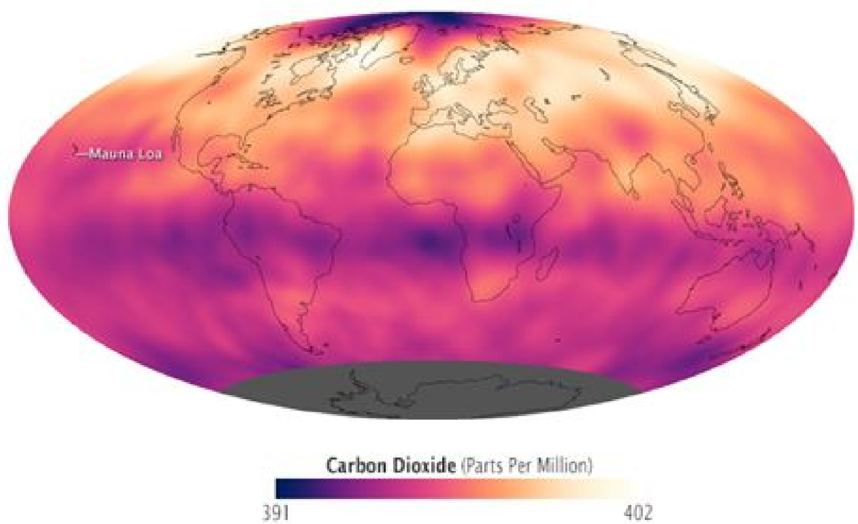

Figure 3. Carbon dioxide distribution infrared image made by the AIRS instrument. Photo NASA.

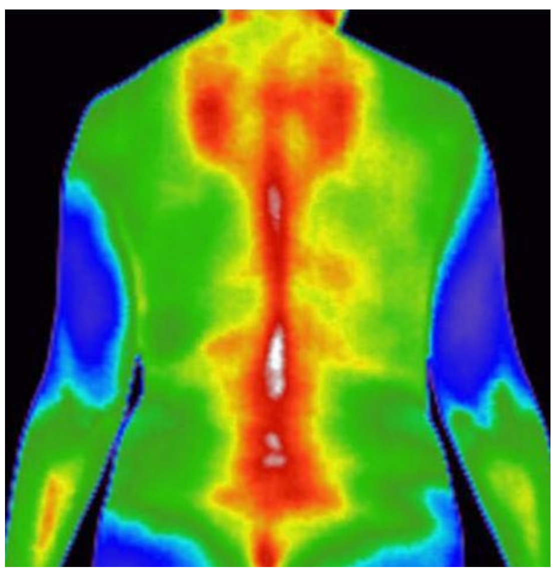

Figure 4. Temperature differences revealed by thermal imaging can assist identification and diagnosis. (Photo credit: Advanced Thermal Imaging, Raleigh, NC)

IR Coating Materials

There are multiple candidates for IR coating materials offering different optical and physical properties. A companion article in this issue of CMN, "Materials and Deposition Technology for Coating Optical Surfaces" presents a discussion on IR and general coating technology.

The material choices vary with spectral region: oxide compounds can be used from Near-IR through Mid-wave IR wavelengths (1 to ~5 µm), fluorides, Ge, and ZnS or ZnSe are required for Long-wave IR because only these materials are transparent at wavelengths longer than ~7 µm. The materials that are used in refractive index combinations to produce coatings for various IR spectral regions are listed in *Table 1.*

Table 1. Materials typically used to make IR coatings.

IR Region wavelength (nm)	Low index n < 1.6	Intermediate n ~ 1.6-1.8	High index n ~2 to 4
SW-MWIR: 1100 - 5000	SiO_2	Al_2O_3, Y_2O_3, SiO	Ta_2O_5, $LaTiO_3$, HfO_2, Si
LWIR: 5000 – 12000	CeF_3, YF_3, YbF3, LaF_3	--	ZnS, ZnSe, Ge

Examples of combinations of candidate materials are given in *Table 2*. The choice of the material combination is dependent on substrate type and the environmental exposure requirements of the coating. For example, coating designs that use ZnS are restricted to substrate temperatures near 150^{o} C.

Table 2. Combinations of materials for IR regions.

SW-MWIR: 1100 – 5000 (nm)	LWIR: 5000 – 12000 (nm)
SiO_2 with Ta_2O_5 or $LaTiO_3$, or Si	CeF_3, YF_3, YbF_3, LaF_3 with ZnS, ZnSe, Ge

Replacements for Thorium Fluoride in LWIR Coatings

During the past three decades, since the use of radioactive materials such as ThF_4 was forbidden in optical coatings, there have been numerous independent research studies regarding a replacement for long wave IR coatings. There has been progress toward introducing and optimizing replacement coating materials that transmit to 13+ µm. It was recognized that the ThF_4 replacement needed to be derived from other fluoride compounds that have a similar index and low absorption, as well as the required mechanical durability properties: low intrinsic (tensive) stress, good hardness, and insolubility.

Materion's CIROM-IRX™ is one replacement composition that exhibits all these desired properties. Yttrium fluoride and ytterbium fluoride have been excellent candidates known for many years, but until recently did not possess the evaporation behaviors needed for low maintenance coating production. Fluoride compounds are somewhat hygroscopic and water soluble, and cannot be grown to thicknesses greater than ~2 µm because of intrinsic stress accumulation. CIROM-IRX™ and other mixed compounds have reduced that problem.

Refinement of YF_3 and YbF_3 materials by Materion in order to achieve trouble-free evaporation has increased the IR coating designer's available materials selection. Yttrium fluoride has been refined to the status that water absorption bands at 2.9 µm and 6.3 µm are essentially absent, and problems such as particulate emanation ("spitting") are eliminated. *Figure 5* shows transmission curves of YbF_3 on a ZnSe substrate and illustrates the high transmittance to the 13 µm region.

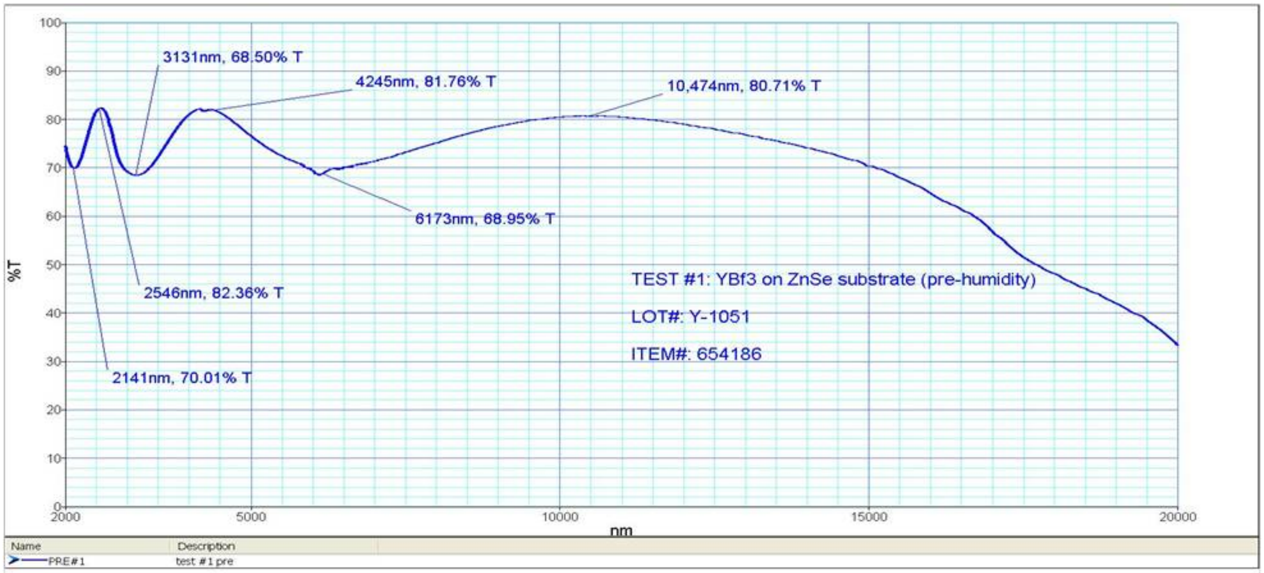

Figure 5. Transmittance of YbF_3 on ZnSe. Thickness 1QW at 11 µm. The shallow depths of the water absorbing bands and high transmittance to 15 µm indicate the superior performance of this ThF_4 replacement material.

Summary and Materion Assistance

Given the increasing importance of IR technology and its coatings, future improvements in coating materials and sensors will enable even more applications to be developed and made affordable to commercial as well as industrial and government markets. Materion has been at the cutting-edge of Research & Development for optical coating technology and a leading supplier of materials.

For more information, please contact Andrew Cohen, Product Marketing Manager, Andrew.Cohen@Materion.com

References

Coating Materials News: "Practical Aspects of Infrared Technology"
Coating Materials News: "IR Coatings Designs and Applications"

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