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The desire to "see" in complete darkness or through obscurants such as smoke or fog has driven the development and adoption of thermal imaging technology in numerous industries. Thermal imaging is the translation of a scene's heat signature-the Long Wavelength Infrared (LWIR) energy produced by a scene in the 8µm to 14µm waveband-into digital data that can be used to produce a visible image or be fed into a computer for interpretation. Because the thermal energy of a scene is independent of reflected light and because it can travel through obscurants with small particle sizes, thermal imaging is the technology of choice for imaging in the dark or other difficult environmental conditions.

Optical Thermal Imaging – replacing microbolometer technology and achieving universal deployment

Despite the reduced cost of thermal imaging available with today's uncooled sensors, there are still millions of potential users for whom thermal imaging is unattainable. A typical uncooled camera may cost in excess of $10,000, too much for most potential users. For example, thermal imaging is critical for firefighters because it helps them locate downed victims, pinpoint the source of a burn or escape a dangerous building.

There are four characteristics that have to apply to make thermal imaging cameras universally deployable.

Cost is a major factor in making thermal imaging accessible to anyone who needs it. One way to achieve that is to use technology that is easy to manufacture even in modest volumes. In addition, these cameras would also have to be easily scalable, low power and provide a good image quality.

Today's technology – the microbolometer

The most common form of thermal imaging technology available today is the microbolometer sensor. Microbolometers are built using vanadium oxide (VO_x) or amorphous silicon (a-Si) processes. Typical prices for microbolometer-based cameras range from $8,000 to $20,000 depending on resolution, performance and feature set.

Microbolometer pixels are very complex. The pixel is shaped like a table with two legs that separate it from a substrate and read out integrated circuit (ROIC) below. The "table" is made of electrically conductive material such as VO_x and forms a complete circuit with the underlying electronics. When incident LWIR energy strikes the "table top" the electrical resistance of its materials change. More incident radiation causes a greater change in resistance. This change in resistance can be probed by passing a current through the device. Therefore, changes in temperature can be read out as electronic signals and used to produce an image. One of the reasons that the pixel design becomes complex is that the "legs" must both thermally isolate the pixel (in order to produce response) and conduct electricity (so that response can be probed). It is not straightforward to produce both results with a single design.

A complete microbolometer camera engine includes several elements: optics, the microbolometer sensor (which consists of sensing pixel array, ROIC, and vacuum package) and back-end electronics. **Figure 1** illustrates the system configuration of these elements.

The microbolometer sensor is manufactured using a micro-electro-mechanical system (MEMS) process, typically in a custom foundry with specialized VO_x processing capability. First a custom ROIC wafer is manufactured. This includes complicated circuitry required to interpret the thermally induced resistance variations. Then pixel arrays are deposited on this wafer. A typical pixel design is fairly complex and can require in excess of 30 mask layers when the underlying CMOS layers are included. Once the pixel arrays have been deposited, the wafer is diced into individual die which are yielded and vacuum packaged to create a finished microbolometer sensor. The sensor is then integrated into control and processing electronics and LWIR optics are also affixed. The complete engine is calibrated for performance over ambient temperature and is then ready for sale.

Examination of the microbolometer structure, materials and manufacturing process make it clear why this technology is unable to fulfill the requirements of universal deployment.

Because microbolometers are manufactured in dedicated foundries with highly complex multi-mask step designs, their average cost is greater than $7,000 and this cost is unlikely to come down due to the use of custom ROIC electronics, expensive die-level packing as well as other exotic materials.

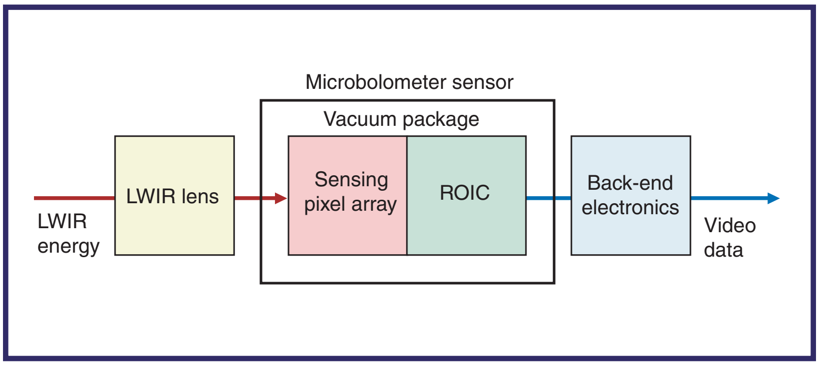


Figure 1. Microbolometer camera engine block diagram.

Scalability is also very limited due to the high development cost of new products, which often take several years to develop.

When it comes to power consumption, advanced microbolometer cameras consume around 2W for normal operation, which is certainly a good performance, but there is room for improvement.

Image quality wise, microbolometer cameras have done well in demonstrating sufficient sensitivity for current applications, but future potential may be limited for smaller pixels. The best possible response for VO_x microbolometers is a 2.5% change per in signal per degree C change in temperature.

Optical Thermal Imaging – the key to universal deployment

It is clear from the discussion of microbolometers that a new technology – with significant changes in underlying design, materials and manufacturing processes – is required in order to

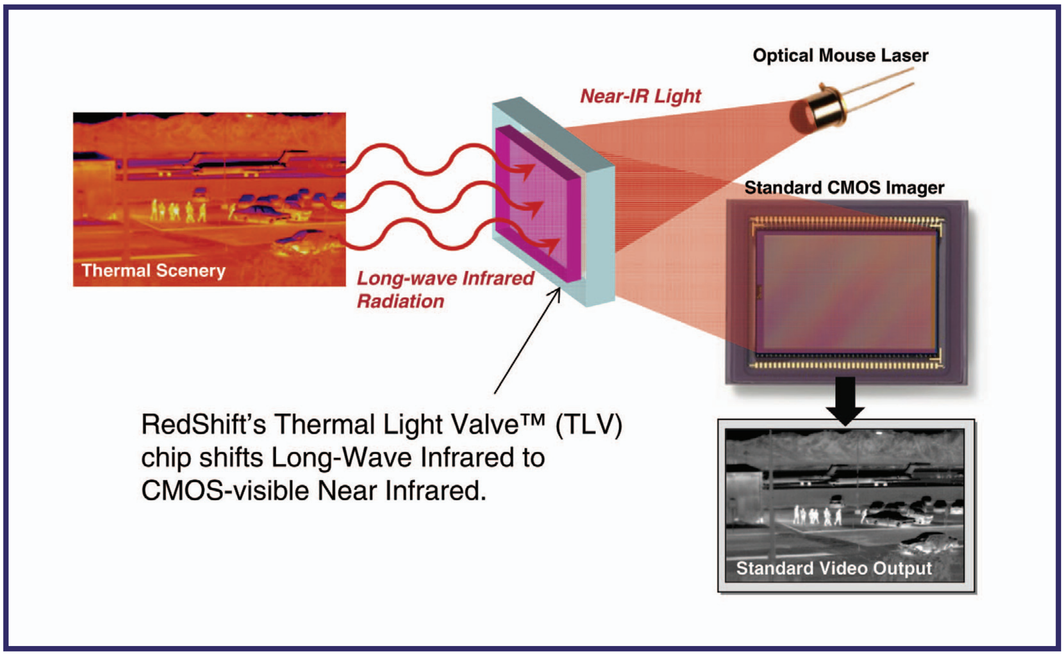


Figure 2. TLV-based Optical Thermal Imaging system.

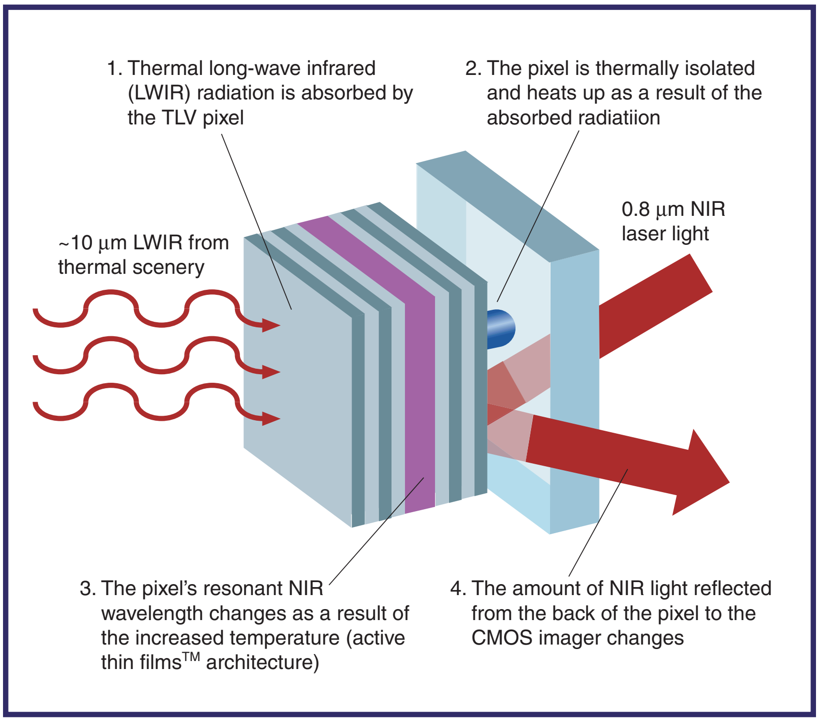
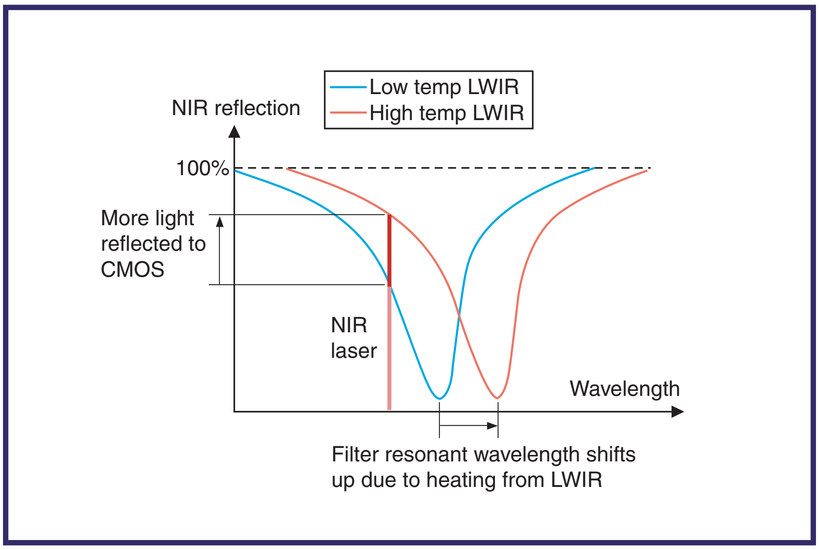


Figure 3. TLV pixel structure.

make universal deployment of thermal imaging a reality. That technology is Optical Thermal Imaging. RedShift Systems Corp. has developed the Thermal Light Valve™ (TLV), a passive optical component that makes Optical Thermal Imaging a reality.

Optical Thermal Imaging does not rely on the change of resistance to measure temperature changes. Instead, Optical Thermal Imaging technologies rely on changes in optical properties when exposed to temperature changes. Such changes are optically read out, rather than electrically read out, using standard digital camera electronics. **Figure 2** shows an illustrative system configuration of an Optical Thermal Imaging system using a Thermal Light Valve (TLV).

Figure 4. Reflection of the NIR signal.



The TLV is composed of narrow-band optical filter pixels standing on thermally resistive posts on an optically reflective and thermally conductive substrate (**Figure 3**).

Each pixel acts as a passive wavelength converter. Long-wavelength infrared (LWIR) radiation from the scene is imaged onto and absorbed by the TLV. This heats up select thermal pixels on the array in direct relation to the thermal signature of the scene. The minimum reflective wavelengths of the pixels shift based upon the thermal energy incident on each. A narrow-band near-infrared (NIR) light source is used to "probe" the temperature of the pixels across the TLV. This NIR probe (**Figure 4**) signal is reflected off the TLV in varying amounts, depending on the pixel temperature, onto the CMOS imager. The intensity of the light received by the CMOS imager is therefore "modulated" by the heat signature of the scene. A thermal image is obtained by measuring the pixel-to-pixel variation in transmission of the NIR probe signal using CMOS imagers.

The TLV tunable optical filter is a Fabry-Perot (FP) structure. It is constructed from amorphous silicon (a-Si) and silicon nitride (SiN_x) thin films, which have been used extensively for many years in solar cells and flat panel displays. These materials are deposited using plasma enhanced chemical vapor deposition (PECVD), which is capable of producing uniform, dense materials in high volume manufacturing environments. The optical filter's minimum reflective wavelength depends on the optical thickness of the cavity – a product of physical thickness and index of refraction. RedShift achieves tunability by changing the index of refraction. The materials are characterized by a high thermo-optic coefficient, which is defined as the change of index of refraction per degree of temperature change.

This discussion demonstrates that temperature induced changes in optical materials can be used to produce thermal imagery, but it does not address the issue of whether Optical Thermal Imaging is superior to microbolometers in terms of universal deployment. For this we need to examine the system diagram of an Optical Thermal Imaging camera engine (**Figure 5**).

Several important differences from the microbolometer should be noted:

1. The sensing array is not an electronic device. It is purely passive layer of optical thin films on glass. This greatly simplifies manufacturing and packaging.

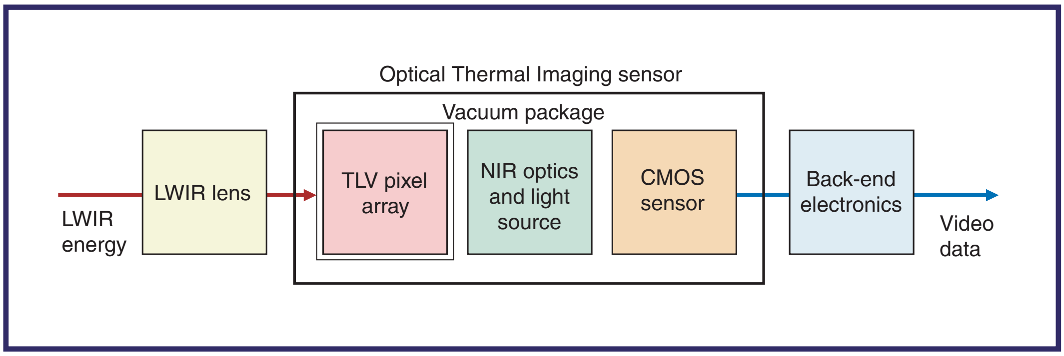


Figure 5. Optical thermal imaging TLV-based camera engine block diagram.

2. The sensing array is manufactured in a standard MEMS foundry, thereby taking advantage of foundry economies of scale to dramatically reduce manufacturing cost over that obtainable with custom fabrication lines.

3. The readout circuit in the Optical Thermal Imaging system is not physically coupled to the sensing array, nor is it a custom design. It consists of off-the-shelf parts, such as laser diodes and CMOS sensors that can be sourced from high volume optical mouse and consumer camera applications and managed independently from the sensor array. This reduces cost, increases yield and reduces development cycle time.

These differences are critical. The following list illustrates that they are instrumental in making Optical Thermal Imaging and TLV cameras highly suitable for universal deployment.

Low cost? Yes.

- Optical Thermal Imaging based cameras will be available for under $3,000 in low volumes and will rapidly decrease in price over time and volume.
- The sensing array-in this case the TLV™ is manufactured in standard semiconductor foundries so no capital investment is required.
- The TLV requires only 4 mask steps to produce. This means it is less costly to manufacture and has much higher yields.
- The ROIC is not yielded with the array.
- The TLV can be packaged using wafer scale techniques which significantly reduces the cost of packaging.
- The ROIC consists entirely of inexpensive off-the-shelf components such as optical mouse lasers and CMOS sensors that are sourced globally and manufactured in extremely high volumes.

Easily scalable? Yes.

- With Optical Thermal Imaging, new products will be released on a time scale consistent with consumer products. Since the pixel's thermal isolation does not also have to be electrically conductive, the design is much simpler and can be easily scaled.
- A change in sensor component is all that is required for new designs.

Low power? Yes.

- Optical Thermal Imaging engines will consume well under 1W. The TLV is passive. It consumes no power. The back-end electronics are the same as a digital camera.

Good image quality? High potential.

- The thermo-optic materials used in Optical Thermal Imaging are very sensitive to temperature changes. The percent change in signal for a one degree change in temperature is up to 20 times higher in Optical Thermal Imaging than in microbolometers.

This analysis demonstrates that to satisfy the strong demand for thermal imaging a major technological shift is required. The comparison between microbolometers and Optical Thermal Imaging demonstrates that only the latter can deliver on the requirements of universal deployment.

Daniel Ostrower (dostrower@redshiftsystems.com) is Senior Director of Product Management for RedShift Systems, Inc., manufacturer of the Thermal Light Valve™. RedShift Systems enables the mass-market application of Optical Thermal Imaging with consistent quality for security, firefighter, first responder, automotive, industrial and other markets where delivering universal deployment is critical. RedShift manufactures components and module solutions that enable OEMs to address new or poorly penetrated markets.