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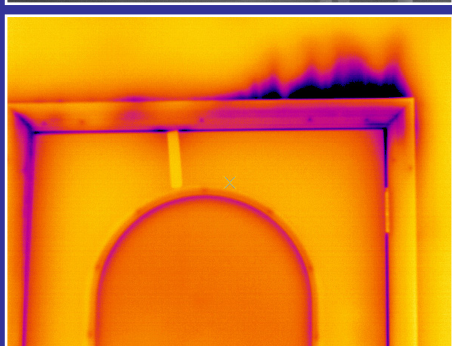
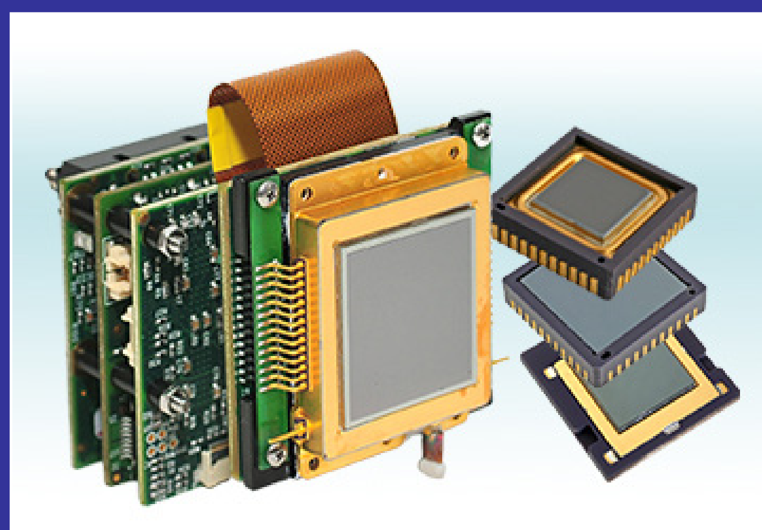
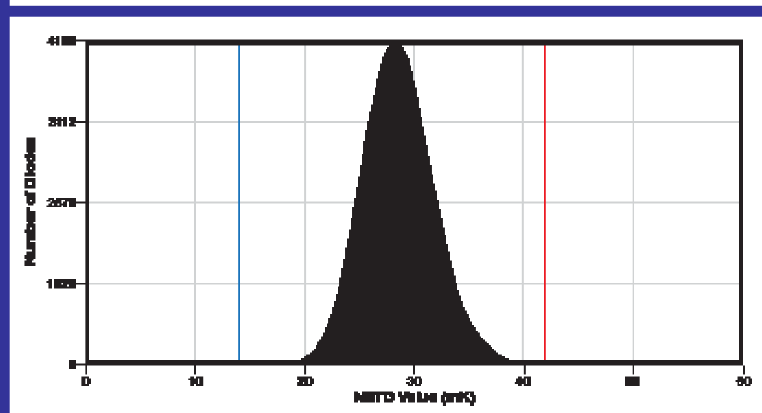
Uncooled Infrared Imaging: Higher Performance, Lower Costs







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Uncooled Infrared Imaging:
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Background

Manufacturers of infrared cameras find a wide choice of uncooled infrared cores available for use in different model designs intended for a variety of commercial, industrial and military products.

Figure 1: Thermal image obtained with 1024x768 a-Si microbolometer detector shows both high sensitivity and resolution. *Courtesy ULIS.*

Uncooled infrared detectors have realized many significant technology advances, improved reliability, better manufacturability and lower costs. This has fueled the availability of a wide variety of infrared cameras based on those detectors. Low cost portable and fixed infrared cameras as well as high performance systems have been introduced for a variety of thermal imaging applications. As a result of the new price points and better overall performance, traditional markets for infrared cameras have exploded while new markets have been created that benefit from the steady improvements in performance.

This article reviews how uncooled detectors have matured into the mainstream markets for infrared imaging. Significant performance improvements are described such as sensitivity, resolution, thermal time constant and uniformity as well as the benefits to system complexity and cost. Infrared camera cores are now available that deliver the performance and versatility required from OEMs to meet specific requirements. Primary applications for thermal imaging cameras are also reviewed.

Uncooled infrared detectors have become an excellent alternative to the cooled detectors and are much more commonly used in many commercial, industrial and military IR camera products. Since they do not require the use of a cryogenic cooling unit, infrared cameras that use uncooled detectors enjoy substantial advantages in maintainability as well as a significant reduction in the size, complexity and cost.

The primary type of uncooled detector today is the microbolometer, a device based on microelectromechanical (MEMs) technology. When infrared radiation in the wavelength range 8-14µm strikes the microbolometer's detector material and is absorbed, it heats up and the resulting change in its electrical resistance is the basic sensing

Amorphous silicon microbolometers developed using MEMS technology have all the advantages of silicon processing including cost and yield, plus are highly sensitive to infrared radiation.

technique. These changes are processed by separate core electronics to create a thermal image. These detectors are quite sensitive and are able to sense heat radiated from objects depending on their temperature.

The two most common microbolometer detector materials are amorphous silicon (A-Si) and vanadium oxide (VOx), referring to the material on the outermost thin film layer. Microbolometers are manufactured using sophisticated surface micromachining techniques to produce very thin membranes that are very sensitive.

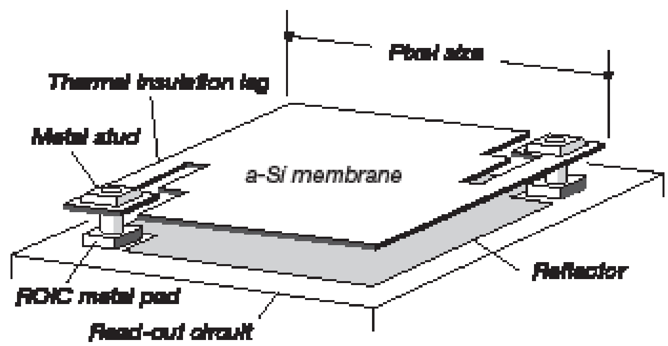

Figure 2: Microbolometer pixel

Because amorphous silicon is inherently stiff, microbolometers manufactured with this material can be made with very small bridge structures. As a result, A-Si microbolometers exhibit higher effective thermal insulation and shorter thermal time constants compared with VOx based devices due to thinner membranes. As shown in Figure 2, the microbolometer pixel is quite simple in structure, so reducing pixel size does not require a complex design since the structure scales appropriately. As a result, the number of fabrication operations in the manufacturing process is optimized.

Amorphous silicon detectors have benefited from widely available silicon fabrication processes. In addition, they have also benefited from a great deal of research performed in improving the performance of similar silicon- based devices, such as solar cells and flat panel displays, with particular attention on pixel operability and uniformity. While other

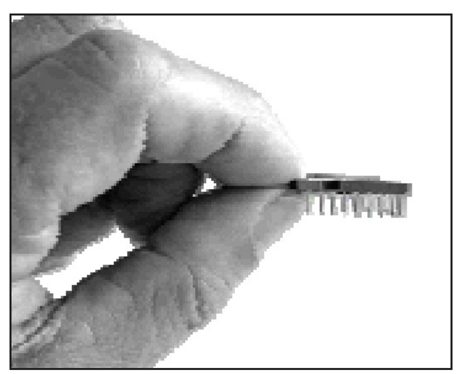

Figure 3: Uncooled Microbolometer Detector having small, low-cost ceramic package.

detector materials such as VOx have shown slightly better noise figures, the technological benefits of amorphous silicon pixels and high yield silicon manufacturing processes have rapidly popularized this technology. Thirty years of manufacturing in the silicon industry have resulted in a mature process that enjoys high manufacturing yields with low defect rates.

As shown in Figure 3, these detectors can be economically packaged in an extremely thin ceramic package specifically designed for the detector. The array is integrated and subsequently sealed under vacuum without the need for any pinch-off. The design of the package allows for a 15-year storage lifetime at room temperature of the detector package.

Microbolometer Technology Advances

Since their initial development, amorphous silicon (A-Si) microbolometers have substantially matured. Technological breakthroughs have occurred at a constant pace, resulting in improvements in performance (such as resolution and sensitivity) as well as in detector packaging. Pixel uniformity and operability have also continued to improve as well due to production changes.

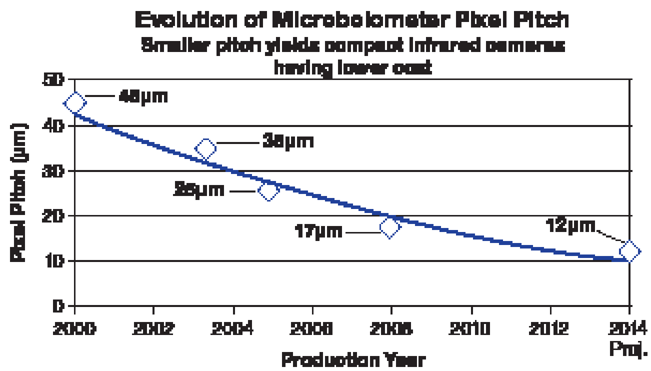

Figure 4: Microbolometer pixel pitch has continued to shrink due to technological advances.

As shown in the chart in Figure 4, over the past ten years, A-Si IR detector arrays have seen a steady reduction in pixel pitch from 45µm back in 2000 to 17µm pixel pitch in 2008. The next generation arrays are projected to have a 12µm pixel pitch geometry, further reducing the size of detectors and optics as well as the size of infrared cameras.

In conjunction with pixel pitch reductions, a variety of array sizes have been introduced. As shown in Figure 5, low resolution 80x80 arrays are now available as well as large format high definition 1024x768 arrays. In light of the reduction in pixel size and the increase in resolution, a variety of applications can be realized.

Thermal Time Constant: Thermal time constant is one of the most important parameters in the design of an infrared imaging detector exceeding the importance of other parameters. Again, because of the intrinsic properties of silicon, A-Si pixels can be produced with very thin microstructures because of their rigid behavior. With these thin microstructures, pixels exhibit a very low thermal conductance between the pixel and substrate and low suspended thermal pixel mass. This results in pixels having a very short time constant and very fast response time which is an enormous benefit for any infrared detector. It is commonly accepted that pixel response times should not exceed one-third of the reciprocal of the frame time (i.e. 10ms for an array operating at 30Hz). This is easily achieved with A-Si pixels. The short thermal constant enables infrared cameras to produce superior thermal image quality even on mobile platforms and while imaging moving objects.

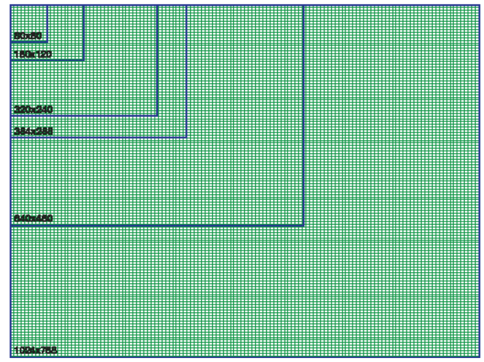

Figure 5: A wide range of array sizes are now available, from 80x80 pixel arrays, for use in economical infrared sensors to 1024x768 pixel arrays for very high resolution products.

Image Uniformity: As with other imaging arrays, each microbolometer pixel has its own intrinsic response. During the manufacturing process, each array can be characterized by its disribution of response values (e.g. gain and offset). Because silicon manufacturing methods are well-established, and due to the simplicity of the structure of amorphous silicon microbolometer,

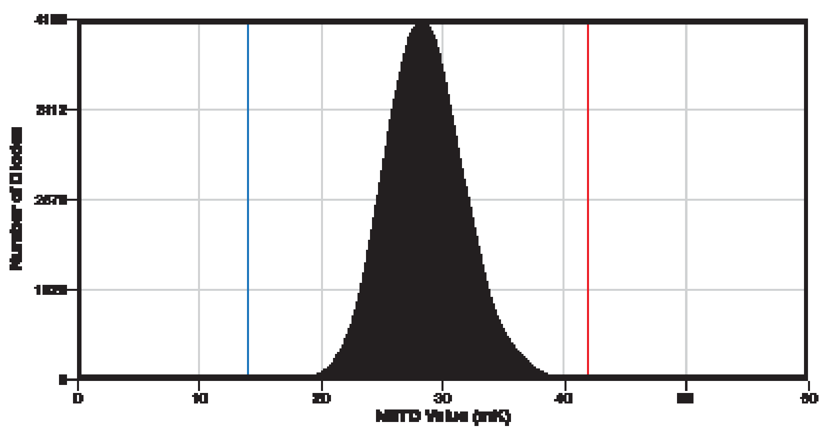

Figure 6: Excellent array uniformity is an important characteristic that assures reliable ambient temperature calibration.

For portable 30Hz infrared cameras, it is highly desirable to have pixel response times shorter than 10 ms. This is easily achieved with a-Si pixels.

array response is quite uniform and distribution characteristics as shown in Figure 6 very narrow. Excellent array uniformity means that gain can be significantly increased prior to digitization and overall system signal-to-noise performance dramatically improved.

Because of their intrinsic uniformity, operating A-Si detectors has other important advantages over other types of microbolometer detectors. For example, since the A-Si pixels can only have one activation energy that defines the bolometer resistance as a function of temperature, knowing the pixel resistance at one temperature is sufficient for prediciting the resistance at other temperatures. Microbolometer arrays manufactured with a composite of materials (e.g. VOx) have numerous factors that impact the response of the pixels in the array and are not so easily characterized. Consequently, they exhibit higher non-uniformity characteristics and are more difficult to operate in TEC-less mode since the wide variation in response cannot be easily predicted. In addition, if not appropriately compensated, some of the pixels in the array may appear saturated, having a response outside the detector digitization range. Because of the high uniformity of A-Si detector arrays, the raw signal delivered by the detector is sufficiently uniform to be processed without any additional electronics, which reduces system complexity, calibration, yield, power consumption, size and finally cost of the overall system.

Array Operability: The operability of an IR detector array is defined by the number of defective pixels in the array, or the percentage of defective pixels. Highly uniform arrays have a smaller number of bad pixels since pixels are defined as defective if their characteristics are significantly different than the average. To achieve the best image, array pixel response should be as uniform as possible across the surface of the device prior to any non-uniformity correction. Amorphous silicon detectors traditionally offer high operability rates partly because of the simplicity of silicon technology and the benefits of established processes. Operability of better than 99.5% is standard in amorphous silicon detectors and rates as high as 99.9% are not uncommon.

Uncooled Infrared Cores for OEM Applications

Uncooled microbolometer camera cores are now available for use in a variety of military and commerical products, both fixed mount and portable, high performance or low cost.

Because of the improved reliability, better manufacturability and lower costs of uncooled infrared detectors, the availability of infrared camera cores has dramatically increased to the benefit of original equipment manufacturers and product designers. Uncooled microbolometer camera cores are now available for use in a variety of military and commercial products, both fixed mount and portable, high performance or low cost.

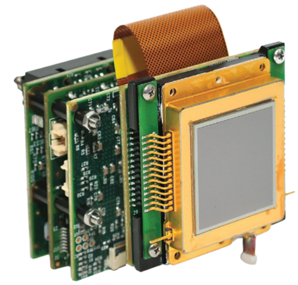

Figure 7: A high resolution 1024x768 uncooled core for high performance military and commercial infrared imaging applications.

High performance cores: Advancements in uncooled IR FPA technology have continued at a steady pace. Developments in new higher performance detectors have resulted in the introduction of high definition and highly sensitive infrared cameras and cores. These advances have lead to improved systems for military applications (driver's vision, wide area surveillance, distributed aperture, 360SA) and demanding commercial infrared imaging systems (thermal imaging, security).

Figure 8: Very high performance uncooled infrared camera cores are available with high definition and continuous zoom.

With a combination of low power electronic designs and effective calibration methods, multi-purpose uncooled camera cores are now available that deliver far better performance than previous uncooled solutions with frame rates over 60 Hz. Despite their high performance, the camera cores are often optimized for size, weight, and power (SWaP). Commercial-Off-The–Shelf (COTS) and custom cores are now available which use a variety of infrared imaging lenses, including continuous zoom, extremely wide angle and telephoto.

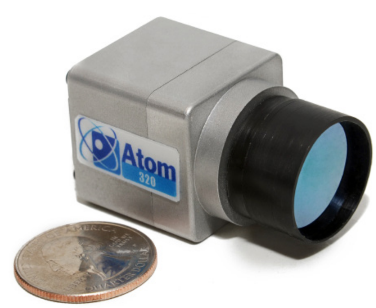

Figure 9: Miniature uncooled infrared cores are possible because of compact electronics and space efficient designs.

Lower costs: As a result of new technology and expanded manufacturing capabilities, new IR sensors are also being developed for high volume applications. Many significant advances have resulted in improved technology, higher reliability, better manufacturability and lower costs. IR sensors will be available with new packaging technologies, such as Pixel Level and Wafer Level Packaging (PLP and WLP) which involve packaging the IR FPA at wafer level. The resulting new price points are opening new commercial markets and expanding existing ones for infrared imaging. This has fueled new camera core developments based on those detectors for use in a wide variety of custom products. Portable and fixed infrared cameras are expected for a variety of thermal imaging applications including automotive, industrial inspection, energy loss and security.

Applications

Amorphous silicon detectors are ideally suited for many IR applications due to their high performance, high reliability and lower cost. Applications for microbolometers exist in both commercial and military sectors. Some of the top applications are as follows:

Surveillance

Because of the high contrast between humans and vehicles, uncooled IR detectors are an ideal choice for surveillance application. Surveillance applications encompass many different areas including, night vision, security, and basic surveillance. Because of the technological advances including 17μm pixel pitch and large format detectors, A-Si microbolometers are finding their way into many more military and commercial night vision applications. For example, one military application that benefits from these advances is unmanned aerial vehicles (UAVs) which require lightweight and reliable IR detectors that can stand physical punishment including high vibrations and high G force loads. These requirements make uncooled A-Si microbolometers ideally suited for this application.

Figure 10: Uncooled infrared cameras are ideal for night-time surveillance applications.

Firefighting

Another application for IR detectors is firefighting. Firefighters are often thrust into situations where visible light cannot be used due to smoky conditions. In low visibility conditions, finding trapped victims or downed fire fighters can be near impossible. Thermal imaging cameras have allowed fire fighters to see through the smoke and locate trapped victims and firefighters. Additionally, Thermal imaging allows for the detection of hot spots after a fire is extinguished, as well as to find the source of active fires.

Figure 11: Because infrared cameras can see through smoke, they are a valuable tool for firefighters.

Industrial Inspection

Certain infrared cameras can be calibrated so that they provide for the non-contact measurement of object temperature. These find plentiful applications in industrial inspection. One of the most common uses of these radiometric infrared cameras is in industrial environments having high power usage. Inspectors use IR cameras for thermal analysis of electrical and mechanical components for problem prevention and detection. In these systems, excess heat can be a sign of a potential problem. Infrared cameras are used to scan for many different issues including loose or dirty connections, overloaded circuits, plugged cooling lines in transformers, and much more. Additionally, the technology is non-invasive and non-destructive and allows for the testing of many points per day.

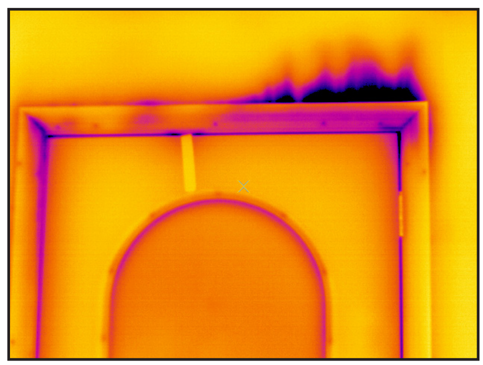

Figure 12: Identifying unexpected heat loss in electrical connections has been found to be key in preventing costly failures to occur.

Energy Conservation

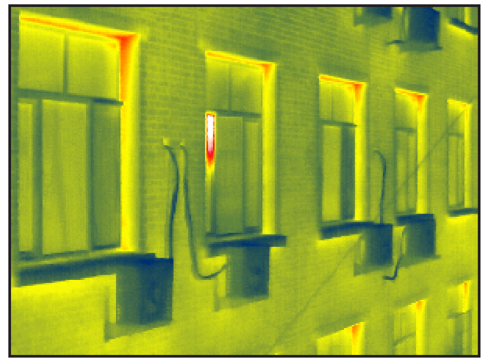

Figure 13: With rising energy costs, identifying heat loss in homes and buildings has become a valued application for infrared cameras.

According to the US Department of Energy "heating and cooling account for 50 to 70% of the energy used in the average American home. Inadequate insulation and air leakage are leading causes of energy waste in most homes"]. Energy conservation is a booming industry fueled by higher energy costs, global warming, and dwindling natural resources. In an effort to make homes and businesses more energy efficient, energy audits are becoming more commonplace. IR detectors and thermal imaging technologies provide an easy to use tool for conducting energy audits. energy audits primarily focus on evaluating the effectiveness of insulation and seals around exterior doors and windows in addition to looking for gaps or cracks that are leaking energy. In addition, thermal imaging cameras can save time and money in detecting leaks in pipes as well. Both in wall and buried pipes can be quickly scanned without the need to destroy a wall or dig up a pipe. Common applications include: hot water leaks in buried pipe, oil and gas pipeline leaks, and leak detection in municipal water mains.

Medical Monitoring

Figure 14: Fever screening cameras are now commonplace at airports and other transit locations to monitor travelers having elevated body temperature.

Infrared cameras have become quite popular at airports and other transit locations for non-contact "fever screening" where public health officials can swiftly scan and measure the skin temperature of people as they pass. Individuals showing an elevated temperature can be evaluated in more detail to help prevent the spread of disease.

Automotive Night Vision

Figure 15: Infrared cameras are now available as an option on many new cars for improved night vision.

Over the last decade IR detectors have become more commonplace in civilian applications. In addition to being used for surveillance, IR detectors and cameras are now becoming standard in automobiles as automotive night vision systems. Automotive night vision systems are used to assist drivers in dark conditions, as well as in bad weather. Automotive night vision systems increase a driver's seeing distance and perception in these conditions beyond the reach of the vehicle's headlights.

Summary

Significant technological improvements have occurred in uncooled microbolometers over the last few years fueling the growth of infrared camera designs that use them. With improvements in sensitivity and resolution and because of a wide variety of available pixel sizes, infrared cameras meeting a variety of application-specific requirements have been introduced. In particular, amorphous silicon microbolometers are shown to have specific benefits in performance (including thermal time constant and uniformity) and cost due to steady technical advances, silicon-based manufacturing advantages as well as yield improvements. Their simplified design, small size and mature silicon-based manufacturing technology have been leveraged to make everything from handheld thermal imaging cameras to night vision systems. Thermal imaging products have found their way into a variety of different applications, including: surveillance, firefighting, industrial inspection, energy conservation, medical monitoring and automotive night vision.

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Edition: 12-17 rev06