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Terahertz Tools Advance Imaging for Security, Industry

Originating Technology/NASA Contribution

On January 16, 2003, the Space Shuttle Columbia launched on mission STS-107. At T plus 82 seconds, with the orbiter rocketing upwards at 1,870 miles per hour, a briefcase-sized chunk of insulating foam broke off from the external fuel tank and struck Columbia's left wing. During reentry on February 1, hot gasses entered the wing through the damaged area of the orbiter's thermal protection system, causing devastating structural failure that led to the destruction of Columbia and the deaths of the seven crew members onboard.

After the Columbia disaster, NASA grounded the space shuttles for more than a year as it worked on new safety protocols to ensure that such a tragedy would not happen again. As part of the preparations for the Return to Flight mission, the Agency required a method for detecting potentially hazardous defects in the external tank's sprayed-on insulating foam prior to launch.

Partnership

NASA Langley Research Center scientists suspected that a new imaging technology called terahertz imaging had the potential to accurately find flaws in the foam on the external tank. Terahertz radiation—lying between microwaves and far infrared on the electromagnetic spectrum—offers imaging capabilities similar to X-rays, but unlike X-rays, terahertz radiation is non-ionizing and thus safe for frequent human use. Terahertz wavelengths can be used to see through many materials and reveal defects like cracks, voids, and density variations. They can be used to image or as an anomaly detector, or both at the same time.

Picometrix, of Ann Arbor, Michigan, was at the forefront of the emerging field of terahertz imaging. In 2000, Picometrix introduced the world's first commercial terahertz system, the T-Ray 2000. The T-Ray 2000 was based upon the company's patented fiber coupling system, but was a non-integrated, workbench-mounted system, which rendered it fine for the research market but impractical for NASA's manufacturing quality control needs. Langley researchers asked the company via **Small Business Innovation Research (SBIR)** agreements to quickly redesign the terahertz systems to be more integrated and deployable into a manufacturing environment.

The space shuttle's external tank is coated in insulating foam that must be checked for defects. To accomplish this, NASA turned to the developing field of terahertz imaging.

> ***Terahertz can be employed as a safer, more precise security measure than X-rays.***

Based on the success of that new prototype system, the company was next asked to deliver a more compact, self-contained terahertz system, the T-Ray QA-1000, and NASA purchased five of the systems for inspecting the external fuel tanks as they were being manufactured by Lockheed Martin. The QA-1000's long, optical fiber umbilicals enabled the system's terahertz sensors to scan the tank from top to bottom. The systems were deployed at NASA's Michoud Assembly Facility and at Marshall Space Flight Center. Langley's original unit was later retrofitted with a similar higher speed delay stage that was also capable of imaging thicker foam.

"This was significant. In addition to the company's patented fiber coupling system that makes Picometrix systems unique, they can also inspect thicker material at substantially higher speed with our T-Ray systems versus others terahertz systems," says Irl Duling III, company director of terahertz business development.

Picometrix became a wholly owned subsidiary of Advanced Photonix Inc. (API), also of Ann Arbor, Michigan, in 2005. The company's terahertz systems—including its latest, highly compact and rugged T-Ray 4000 systems—were later adopted by Kennedy Space Center as a diagnostic tool for scanning the orbiter's thermal tiles for the remaining shuttle flights. The systems offered an effective way of not only inspecting the tiles for hidden damage, but also of precisely locating components underneath the tiles that were in need of attention—

without the costly removal and replacement of extra tiles which often happened before the use of the T-Ray 4000.

"With this technology, NASA could scan and see the precise location of wires and antennas and remove only the necessary tiles," says Picometrix engineer Greg Stuk. "In one example, it saved the Agency hundreds of thousands of dollars."

Product Outcome

The imaging capabilities of terahertz make it useful for a wide range of applications. It can be employed as a safer, more precise security measure than X-rays in airports and other buildings, revealing concealed weapons and the contents of packages. Since numerous materials have specific spectral signatures revealed by terahertz radiation, it provides spectroscopic and other unique identification information useful for chemical analysis, pharmaceuticals, and explosives detection. Not only can terahertz see through an opaque pill bottle, for example, it can also reveal the chemical makeup of the pills inside. It can also provide high-resolution imaging down to 200 microns. The industrial possibilities of terahertz range from determining the uniformity of coating thickness to detecting hidden defects to ensure product quality.

The company now offers the T-Ray 4000 Time-Domain Terahertz System commercially. Featuring its patented fiber-pigtailed transmitter and receiver modules, the T-Ray 4000 is designed for both the research laboratory and the industrial setting. The T-Ray 4000 takes the next step beyond the NASA-inspired T-Ray QA-1000 system. While the QA-1000 is about the size of a small refrigerator, the T-Ray 4000 is an easily portable, rugged, briefcase-size system weighing only about 50 pounds. As a time-domain terahertz system, the T-Ray 4000 generates high-speed picosecond (one-trillionth of a second) duration terahertz pulses for scanned spectroscopy or imaging. These qualities, along with the patented fiber-coupled sensor heads that can scan objects of almost any size, make the T-Ray 4000 an easy-to-use tool for terahertz applications beyond the laboratory—though it is useful there as well.

"As far as having a product that you can deploy onto a manufacturing floor, this is the first of its kind," says Duling. He credits the company's NASA work with helping drive this industry-leading advancement.

The T-Ray 4000 Time-Domain Terahertz System, capable of generating high-speed terahertz pulses and equipped with fiber-coupled sensor heads, is a versatile and user-friendly instrument for use in the laboratory and in real-world applications.

"The rest of the industry is trying to figure out how to generate terahertz, how to detect it, how to build a complete system that can be fielded," he says. "In part through NASA's motivation, we've been able to complete that full-system integration and turn it into something we can take out into the field and use as a tool."

"Our systems' features now allow terahertz to access the most obscure places," says Steve Williamson, the company's chief technology officer. "It's a powerful benefit to our customers."

API's terahertz systems can be used for thickness measurements of roofing material, paper and paper coatings, and coatings on films. They also can be employed for pharmaceutical applications like aseptic packaging and tablet production. Art conservationists from prestigious institutions like the Uffizi Gallery and the Louvre have used API systems to date paintings, look for pigment concentrations, and reveal frescos on walls that have been painted over. The technology has been even applied to examine the structure of pagodas in Japan, providing guidance for renovations. These are only a few examples of the benefits of this still developing field, says API CEO Richard Kurtz.

"Terahertz has huge market potential. We estimate there are over $200 million in opportunities for our terahertz systems over the next 7 years," he says. To help API stay at the forefront of the terahertz industry, the company is continuing work with NASA through SBIR contracts with Glenn Research Center. The goal of this partnership is a computed axial tomography time-domain terahertz system capable of creating three-dimensional images.

"There has been great collaboration between API and NASA," says Williamson. "NASA has helped us push the envelope." ❖

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