New Inspection Techniques Using Submillimeter/Far-Infrared Waves

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WHY THE SMMW/FIR SPECTRUM?

Although spectroscopists have carried out experiments in the submillimeter/far-infrared (SMMW/FIR) spectrum for several years, others have found it difficult to utilize this spectral region. Extending from about 50 to 1000 μm, the SMMW/FIR spectrum has not in the past offered a comprehensive group of components and technology that could be favorably compared with, say, the optical or microwave spectrum. Now this picture has changed. The important new development is the optically pumped molecular laser first demonstrated[1] by Chang and Bridges in 1970. From this have come the small cw waveguide lasers emitting moderate power[2,3] (1 to 100 mW) at many wavelengths throughout the band and high-power pulsed lasers[4] with power levels approaching 10^6 W. Also, that other key component, the detector, has been improved with the development of sensitive mixers for detection of coherent radiation.[5,6] As a consequence, a sharp increase in activity in the SMMW/FIR has occurred recently, and new applications to plasma diagnostics, military systems, and inspection techniques are being explored.

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It might seem absurd at first to explore the use of this spectral region for nondestructive tests or for imaging. Since the wavelengths are quite long compared with those of optical and infrared devices, the resolution of SMMW/FIR techniques is destined to

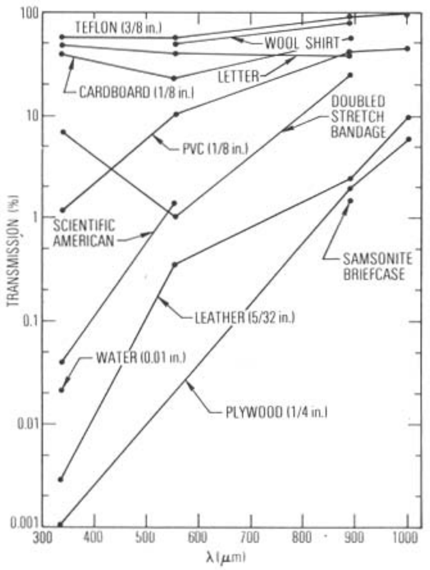

Figure 1. Transmission versus λ of dielectric media, including reflection, absorption, and scattering losses.

be worse by 1 or 2 orders of magnitude. The key idea is that many materials are transparent in the SMMW/FIR spectral region but are opaque in the visible and infrared. Scattering losses are minimized at longer wavelengths, along with lower absorption losses in many dielectric materials. To illustrate the point, some transmission data are shown in Figure 1 for many common materials, which have been chosen with several applications in mind.[7] These data were taken using lasers at 337, 554, 890, and 1.020 μm and a cooled detector. The data points include losses due to reflection, scattering, and absorption. The trend is clear; at longer wavelengths the vibrational (reststrahlen) band absorption decreases, resulting in a monotonic increase in transmission.

Several applications are suggested by these data. For example, objects concealed within cartons or briefcases could potentially be detected. Metal objects are opaque and could easily be detected. Even dielectric objects would show contrast against the surrounding medium at some wavelength, barring a fortuitous match of the transmission properties of object to surrounding medium.

A SIMPLE IMAGING APPARATUS

To demonstrate some potential applications, a very simple SMMW/FIR imaging apparatus was constructed in our laboratory.[8] Small samples, placed on a mechanical stage negotiating a raster scan, are interposed between a SMMW/FIR laser beam and a cooled GaAs photodetector. The detector output is amplified and then used to modulate the light output of an LED affixed to the stage. The subsequent optical rendition of the FIR image is recorded by a film pack. In Figure 2 is shown a typical image, in this case a letter bomb simulated by electronic parts and Teflon "explosive." Even with a coarse raster scan and the presence of electronic "ghosts," the likeness is preserved in the SMMW/FIR.

Although law-enforcement applications are suggested by the above experiment, x-ray equipment is well developed for package and case inspection, and it is not clear that a SMMW/FIR package inspection system would be better if developed. Other inspection situations do favor use of a well-developed SMMW/FIR imaging system. For example, the routine inspection of personnel by x-ray radiation is hazardous. SMMW/FIR radiation is nonionizing, and analyses indicate[9] that no personnel hazard will exist in an actual system[10] employing cw FIR lasers. Our recent measurements with FIR laser illumination show considerable contrast between explosive materials and human skin; hence a SMMW/FIR personnel weapon-detection system offers promise. Details still have to be pinned down. Metallic weapons or explosives concealed on the body covered by clothing are probably best detected by using a laser illuminator as opposed to passive detection of thermal radiation using the small temperature difference between the object and the surrounding environment. Very little contrast was found in earlier work performed with passive detection.[11]

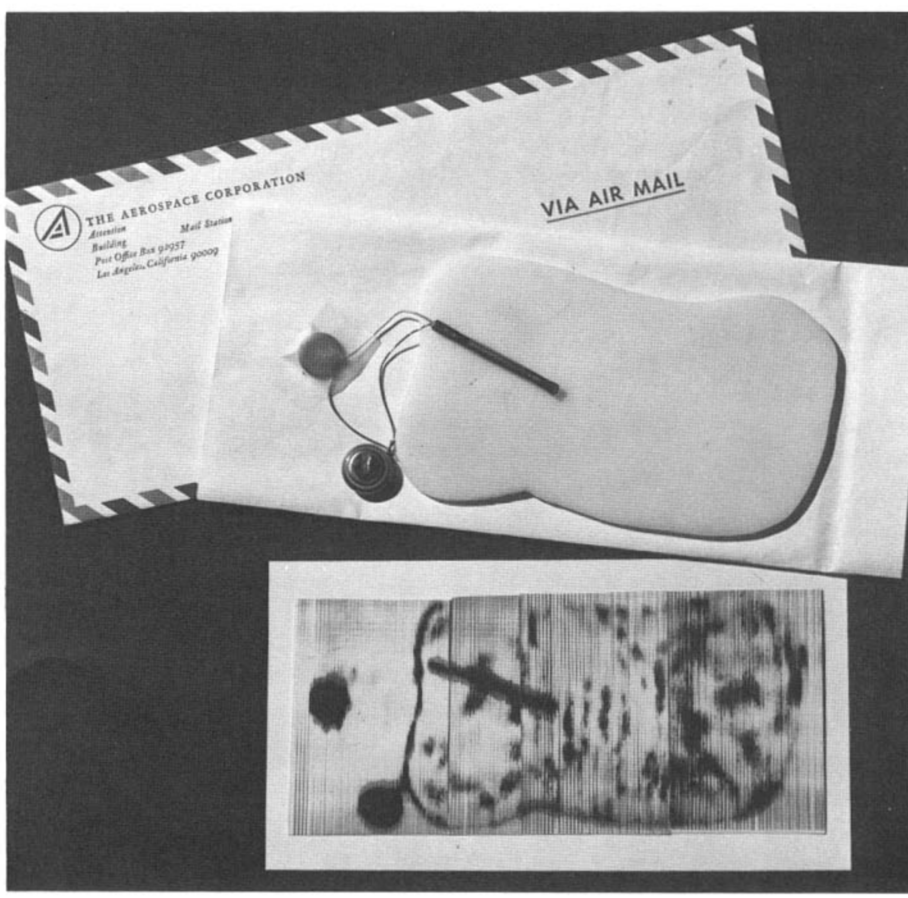

Figure 2. The lower picture is the SMMW/FIR image of a simulated letter bomb taken in transmission with a laser wavelength of 1.22 mm.

NONDESTRUCTIVE TESTING

Perhaps the best application of the SMMW/FIR that has evolved to date is nondestructive testing. Plastics, potting compounds, Fiberglas, and similar dielectric materials play a big role in our daily lives. Using our simple imaging apparatus, we have taken pictures of electronic parts in commercial potted rectifier bridges. More important is the capability of a SMMW/FIR apparatus to detect bubbles and other flaws in dielectric media, a difficult task for x-ray equipment. (Acoustical techniques can also be used in some cases.) P. Cheo at United Technology Laboratories has carried these concepts from a feasibility demonstration by the imaging apparatus to the point where rather detailed measurements can be made. His idea is to configure a dielectric medium void detector using a Mie scattering format.[12] A measurement of scattered FIR laser radiation is correlated to the size and shape of defects. Using a CH_3OH waveguide laser with a cw output power of 400 mW,[3] voids in polyethylene ranging from 150 to 1000 μm in diameter have been detected with good signal-to-noise ratio. Demonstration of this technique is important to the production of low-cost underground power transmission cables. Use of a void detector in the polyethylene insulation could eliminate premature cable failure caused by electrical breakdown at voids, and Dr. Cheo has demonstrated moving-cable flaw detection suitable for production-line quality control.

BIOLOGICAL APPLICATIONS

From the above we can see that a low-resolution SMMW/FIR inspection system can solve real problems in specialized areas. One can speculate about other applications. In Figure 3 is shown a SMMW/FIR picture of a common iris leaf taken from the garden. The upper half of the leaf is green and fully saturated with water; in the visible picture of Figure 3, the contrast between the green upper half and brown (dry) lower half of the leaf is clearly seen. The unaesthetic character of the SMMW/FIR picture derives from the huge absorption of the 337-μm radiation in the green half. From the data of Figure 1, we see that an attenuation of nearly 10^{-4} is produced by only 0.25 mm of liquid water. This suggests biological and other applications involving the detection of water, for example, the state of dehydration of plant and animal tissue or product processing involving wet processing and drying.

This extreme sensitivity to liquid water unfortunately precludes most medical applications. Bone is relatively transparent, but water-bearing media such as human fat, skin, and whole blood attenuate too heavily to permit one to contemplate either imaging of the subsurface or reception of Doppler-shifted returns. Note that stretch bandage, as well as other bandage materials and casts, is fairly transparent, suggesting the possibility of wound inspection.

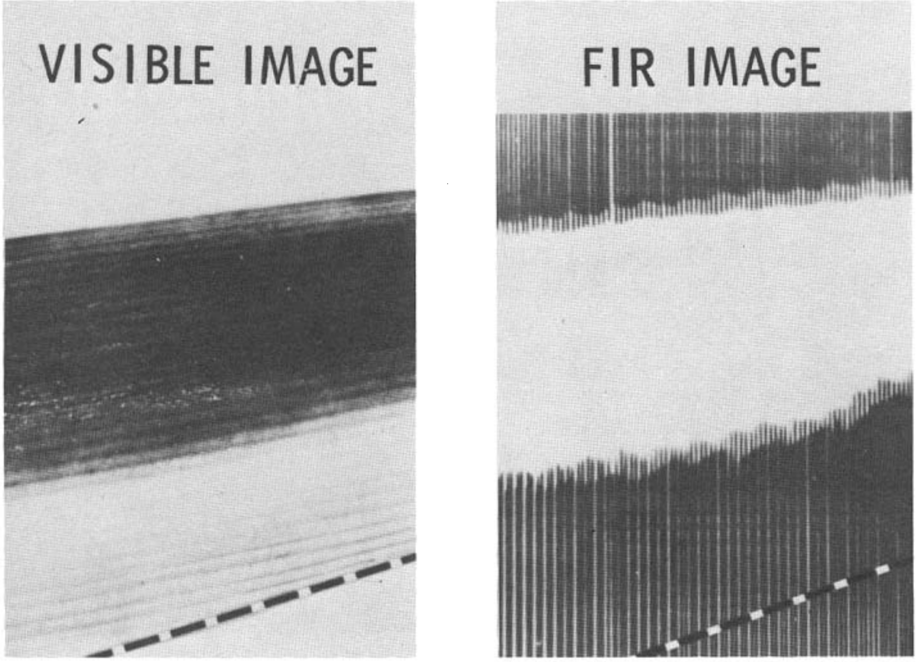

Figure 3. An iris leaf image in the visible (left) and in the SMMW/FIR (right) taken in transmission at a wavelength of 337 μm. The dotted line marks the brown outer edge of the leaf.

CONCLUSION

The feasibility of SMMW/FIR inspection techniques has been established, but it is important to note that the full range of applications is still unexplored. The work described above has been the result of sporadic, low-level activity with matching budgets. Clearly, the topic is in an infancy state, and much more work is needed to firm up the basic ideas. At this early stage, however, it does seem that SMMW/FIR inspection techniques will find specialized uses in many technical disciplines.

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