Infrared Technology—Part 1

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IR technology has always had an element of mystery to it. IR light starts just beyond the visible range. To make up for its lack of visibility, IR radiation makes itself felt as heat, as Sir William Herschel discovered in 1800. More recently, people have found uses for this technology because it is ideal for those applications where visual observation is not meant to yield all the secrets. We cannot see IR radiation, yet it is everywhere.

Herschel discovered IR radiation when he dispersed the solar spectrum with a prism and found thermal effects of the invisible radiation beyond red. Thirty-four years later Forbes discovered that heat radiation could be polarized. The wavelength of near-IR radiation was determined by Fizeau and Foucault three years later. In 1865, Maxwell theoretically described electromagnetic radiation, and Hertz produced electromagnetic waves using an oscillator in 1887. In a similar experiment, Nickols and Tear generated far-IR waves of 0.22 mm in 1923.

IR forms a bridge between physics and optical sciences because it is removed from the empirical thinking introduced by the detection process and the data processing system of humans. Physicists have found IR physics amenable to the kind of scientific analysis leading to new theories.

Lummer and Pringsheim were the first to measure the distribution of radiant energy coming from a blackbody radiation source: It looked neither exactly like the Wien's nor the Jean's law. In 1900 Planck presented a new theory of the distribution of energy among the elementary oscillators in thermodynamic equilibrium with an enclosure at a given temperature, now called Planck's law. The development of the equation, which described the energy distribution for the radiation in the thermal equilibrium with an enclosure, required an explicit assumption about the quantum nature of light, one of the cornerstones of modern physics.

At the same time, Planck's equation is the workhorse of modern IR engineering. It has been integrated, differentiated, evaluated *per partes,* tabulated, expanded in infinite series, and presented in numerous equivalent forms. IR engineers use the concept of the dual nature of light to solve their everyday design problems. They may use Planck's blackbody radiation distribution law expressed either in terms of the number of photons or in the form of continuous energy, distributed over the spectral interval.

Three uses of IR technology have been of importance historically. In the initial applications of IR technology, IR molecular spectroscopy was used for material characterization. Everything emits thermal radiation, therefore remote monitoring with IR radiation is an ideal technique for noninterfering, nondestructive, passive observations. The IR portion of the electromagnetic spectrum is particularly useful for military applications, because the process of watching in the IR is undetectable. Finally, as we have been able to raise our gaze above the Earth's horizons, we have learned that the sky is even more mysteriously beautiful in the IR than in the visible.

Many secrets of the universe remain locked inside the IR mystery. The Earth has an atmosphere that protects its life from the Sun's harmful and abundant IR radiation. Thus, any systematic survey of IR skies requires space-based observations due to the atmospheric effects. Kessler describes the scientific objectives of the Infrared Space Observatory (ISO), scheduled for launch in 1995. The Long-Wavelength Spectrometer on the ISO is described by Clegg. Lemke et al. describe far-IR imaging, polarimetry, and spectrophotometry on the ISO photometer (ISOPHOT). The preflight characterization and calibration of the ISOPHOT is described by Wolf et al.

Recently, interest has been renewed in smaller instruments, because the risks involved in the design, testing, and deployment of instruments favor small missions. A spatial radiometer for earthlimb observations from space is described by Kemp, Larsen, and Huppi.

The atmosphere is mostly opaque to IR radiation. There are several windows, however, where the energy is transmitted by atmospheric gases, but the image is still distorted. The atmospheric effects on image quality and image restoration techniques are described by Sadot et al.

Further out in space, IR sources are becoming accessible to scientific probing instruments because of the developments in detector technology. Detector development appears to be driven by defense needs, yet scientific applications are clearly beneficiaries of this dual-use technology. In recent years, the rapid technology growth of the semiconductor industry for electronics applications has led to detector development as a side benefit for the optics and IR community. Kozlowski et al. describe a high-performance 5-μm 640×480 HgCdTe/CdTe/Al_2O_3 IR focal plane array. Seto et al. describe a 1-Mpixel IR imager with PtSi Schottky-barrier detector elements. Tsaur, Chen, and Marino report on Ge_xSi_{1-x}/Si heterojunction IR focal plane arrays.

Monolithic focal plane arrays have the advantages of uniformity and manufacturability and the disadvantage of a poor fill factor. This naturally leads to using on-the-chip optics in the form of microlens arrays. Kipfer et al. describe the use of microrelief structures to fabricate optical components for use in the IR.

Laser development is an important application of IR physics. Mode competition in a high-power CO_2 laser is described by Arecchi et al. Norgard measures electromagnetic fields in IR correlation experiments. The basic physical laws of the conservation of energy hold in the IR to the chagrin of all IR system designers: IR radiation that is not used in geometrical image formation represents noise. The semitransparent optical materials spread an image of a point due to scattering. Tsai, DeWitt, and Shaffer present the measured spread function for the visible and near-IR wavelengths for several materials.

In addition to the developments in the semiconductor industry, IR technology also owes its growth and maturity to the development of fast computers to perform the large number of ray traces necessary to assist in the design of a good optical system. Some interesting recent IR optical designs are described by Mann. Advances in the computer control of machines that are being used to figure the optical surfaces, such as diamond turning for IR optical components, lead to optical designs incorporating more complicated surfaces, such as prolate spheroids. Optical systems incorporating aspherics require a small number of optical elements, making them light and compact. Although the *schiefspiegler* has been in existence for more than a hundred years, the analytical development showing the image-forming properties of such a system has not been presented until now by Stavroudis.

IR technology has made possible other uses for on-board computers. An integral part of remote noninterfering monitoring is to keep records and make decisions using the collected information. Verga describes a spaceborne autoranging IR viewing system for mapping fluids in a microgravity environment. Scholl describes a smart camera that can identify any star field for the purpose of autonomous navigation.

The spatial and temporal simulation of an IR scene is a difficult task. Barnard, Boreman, and Pape describe the use of a deformable mirror as a light modulator to project an IR scene.

My appreciation to all the authors who took time from their busy schedules to prepare a manuscript for this special section. Even though the majority of the manuscripts were solicited, each and every manuscript underwent a thorough review process: It was reviewed by at least two peers for its technical content, originality, form and level of presentation, and overall suitability for the intended readership. Several reviewers were so helpful that the authors acknowledged the reviewer's contribution in the final manuscript. Here is a nearly complete list of the scientists and engineers who served as reviewers for this special section on IR technology:

Dr. Helmut H. Aumann, California Institute of Technology
Dr. Reinhard Beer, California Institute of Technology
Dr. Charles A. Beichman, California Institute of Technology
Dr. Nathan Bluzer, Westinghouse Advanced Technology Laboratories
Dr. Richard O. Buckius, University of Illinois
Prof. Lee W. Casperson, Portland State University
Dr. Moustafa T. Chahine, California Institute of Technology
Dr. Eri Cohen, California Institute of Technology
Captain Brian Figie, Phillips Laboratory
Dr. Eric Fossum, California Institute of Technology
Dr. Nicholas Gautier, California Institute of Technology
Prof. Joseph W. Goodman, Stanford University
Dr. Samuel Gulkis, California Institute of Technology
Prof. A. Ishimaru, University of Washington
Dr. Robert E. Knowlden, Lincoln Laboratory, Massachusetts Institute of Technology
Dr. Timothy N. Krabach, California Institute of Technology
Dr. Paul W. Kruse, Honeywell, Inc.
Dr. B. F. Levine, AT&T Bell Laboratories
Dr. M. J. Mahoney, California Institute of Technology
Dr. Peter V. Mason, California Institute of Technology
Dr. John C. Mather, NASA Goddard Space Center
Dr. Daniel J. McCleese, California Institute of Technology
Dr. James P. McGuire, California Institute of Technology
Dr. Jonathan Mooney, Rome Air Development Center
Prof. Richard C. Powell, University of Arizona
Dr. Freeman D. Sheperd, Rome Air Development Center
Mr. Warren J. Smith, Kaiser Electronics
Dr. A. T. Stair, Phillips Laboratory
Dr. John R. Tower, David Sarnoff Research Center
Dr. Peter S. Tschen, NASA Lewis Research Center
Dr. Yaujen Wang, Hughes Spacecraft Company
Dr. Wendel Watkin, White Sands Missile Range
Dr. Michael W. Werner, California Institute of Technology
Dr. Erick Young, University of Arizona.

My gratitude to all the reviewers for sharing their expertise and for giving their time to enhance this special section.

I wish to thank Dr. Brian Thompson for giving me the task of assembling the manuscripts for this special section. The response of the IR community to the opportunity to present a compendium of refereed papers describing the state of IR technology was overwhelming, hence, some of the papers appear in this issue and the rest will appear in the March 1994 issue.

I am very grateful to Prof. James C. Wyant from the University of Arizona and the WYKO Corporation, the editor of *Applied Optics*: *Optical Technology,* for teaching me the skills of the editorial profession. I am indebted to Mr. Bernard H. Soffer of Hughes Research Laboratories for advice on how to prepare a balanced special section. I would like to thank Mr. Bjorn Andresen of El-Op, Israel, chair of the IR technology series of SPIE conferences, for many helpful suggestions. I wish to acknowledge Mr. James W. Scholl of the Motorola Computer Group for support and encouragement.

I would like to conclude with a reflection on the recent changes around the world and a hopeful thought. We have found new and exciting applications of IR technology, as illustrated in this special section. The contributors come from 12 countries (Denmark, France, Germany, Israel, Italy, Japan, Mexico, The Netherlands, Spain, Sweden, the United Kingdom, and the United States) and three continents (North America, Asia, and Europe). The international cooperation on the ISO project illustrates that IR technology can bring nations together for scientific exploration and for a better future for all of humankind.

I could not hope to describe the vision of harmony among people and nations better than that master of poetic narrative, Ovid, describing the Golden Age 2000 years ago in the *Metamorphoseon Libri*[1] (known to us as "metamorphoses" or stories of changing forms).

Aurea prima sata est aetas, quae vindice nullo,
sponte sua, sine lege fidem rectumque colebat.
Poena metusque aberant, nec verba minantia fixo
aere legebantur, nec supplex turba timebat
iudicis ora sui, sed erant sine vindice tuti.
Nondum caesa suis, peregrinum ut viseret orbem,
montibus in liquidas pinus descenderat undas,
nullaque mortales praeter sua litora norant;
nondum praecipites cingebant oppida fossae;
non tuba derecti, non aeris cornua flexi,
non galeae, non ensis erat: sine militis usu
mollia securae peragebant otia gentes.

For those of us who have forgotten most of our Latin due to lack of use, I include an eighteenth-century translation[2] that is faithful to the original in its poetic form.

The Golden Age was first, when Man maintain'd
His Soul unclouded, and his Sense unstain'd,
And Truth, and Innocence together reign'd:
Nor Fear nor Punishment compell'd an Awe,
When all were govern'd by unwritten Law.
No Books were then, nor at the Judges Look,
In suppliant Crowds the guilty Pris'ners shook,
Conscience the only Judge, and only Book.
Guiltless of Wounds, the Pine securely stood,
Nor chang'd for distant Seas her native Wood.
Then unambitious Mortals knew no more
Than the short Prospect of their native Shore.
No Walls, nor steepy Bulwarks rais'd in Air,
The Cities girt; as yet no Cities were.
No Hand had yet the wreathing Trumpet made,
The polish'd Helmet, or the murd'ring Blade;
Fearless, and guiltless of the Warrior's Crime,
The happy Nations slept away the Time.

Dare we accept the challenge that the future is ours to make golden?

References

1. *Ovid in Six Volumes, III Metamorphoses, Volume I,* English translation by Frank Justus Miller, Liber I, verses 89–100, pp. 8–9, 3rd ed., Harvard University Press, Cambridge, Massachusetts (1977).
2. Ovid, *Metamorphoses,* translated by Garth, Dryden et al., Amsterdam (1732), Book I, verses 89–100, p. 7, reprinted by Garland Publishing, New York (1976).

Marija Strojnik Scholl completed a classical (high school) education in 1969 and enrolled at the University of Ljubljana, Slovenia, with a major in engineering physics. The next year she moved with her parents to Arizona. She earned the BS and MS degrees in physics in 1972 and 1974, respectively. During this period she performed research on magnetic lenses and published under her maiden name. Dr. Scholl received the MS and PhD degrees in optical sciences from the University of Arizona, specializing in IR. She also earned a MS degree in engineering from the University of California at Los Angeles. As an engineering manager for Rockwell International, Dr. Scholl was responsible for optics technology issues and diagnostics for high-energy IR lasers. While a staff scientist for the Sperry Corporation, she developed a 1500-pixel × 1500-line color projection display system for digital maps and path planning. As a scientist at the Jet Propulsion Laboratory, Dr. Scholl worked on novel concepts for autonomous planetary exploration. She applied optical processing techniques to autonomous navigation, landing, and vision functions. She also developed a star field identification technique to allow an intelligent camera to determine its orientation in inertial space for autonomous optical navigation. Additionally, she taught undergraduate optics at the University of Southern California and radiometry and IR system design at the University of LaVerne. Currently, Dr. Scholl is a senior scientist at Alenka Associates. She is also serving as a topical editor for *Applied Optics* for IR optics. Dr. Scholl is a member of SPIE, the Optical Society of America, the American Association for the Advancement of Science, and Sigma Xi, and a former member of IEEE, the Electro-Chemical Society, and the American Physical Society.