The optics option: preparing for a career in optics

Rudolf Hartmann

Martin Marietta Corporation, Electronic Systems
P.O. Box 628007 MP 1404, Orlando, Florida 32862-8007

We live in a visual world. Without vision, our perception of the environment would be severely limited. Visual stimuli are seen, recorded, and processed in many different ways. Astronomy, the process of imaging distant objects, and microscopy, the process of magnifying minute detail, are extensions of vision. Other extensions of vision include seeing things in different spectra, processing images for enhancement, making decisions automatically, and guiding and controlling sophisticated, complex industrial and military equipment. Optics is the study of this vision and its applications.

Optics is a fascinating field that is growing rapidly. Students and practitioners of optics are attracted to the field for a variety of reasons. Hobbies such as photography, astronomy, and video recording, as well as academic pursuits, such as a high school physics or science project, may spawn an interest in optics; however, college training is the cornerstone of an optics career.

Optics is part of physics, and as such, requires coursework in the areas of geometrical optics, physical optics, spectroscopy, electricity, magnetism, and solid state physics. In addition, mathematics is extremely important for optics design, analysis, and modeling. Optics is the successful synergism of these many disciplines.

Many colleges and universities offer undergraduate and graduate optics curricula. Rochester University's Institute of Optics and the Optical Sciences Center of the University of Arizona are the most prestigious of these institutions. Further, such societies as the Optical Society of America (OSA) and the International Society for Optical Engineering (SPIE) offer a wide variety of valuable short courses, tutorials, seminars, and papers at conferences that are held several times a year.

Traditional optics fields, such as optometry, the examination of the eye and correction of its defects, or ophthalmology, the study of disease and treatment of the eye, are optics-oriented careers. Exciting new fields, such as optical communication, optical computing, phase conjugation, adaptive optics, and holography, are expanding the scope of optics technologies. Development of sophisticated military EO systems presents one of the greatest opportunities and challenges in the optics world today.

Background

The word optics is derived from the Greek opsis, meaning eye. Optics is that part of physics that deals with the origins, propagation, and detection of light. Light in this context includes visible radiation as well as a broad spectrum of electromagnetic radiation, ranging from ultraviolet (UV) to far infrared (IR).

Light is a form of energy given off when an atom transitions from a state of greater to a state of lesser internal energy. The energy lost by the atom during this transition is carried away in the form of a packet of electromagnetic radiation called a quantum of light. The detection of light is the absorption of energy in atoms that produces a chemical change, as in the eye or in a photographic emulsion (film). Light heats bodies, affects photoconductive crystals in voltage generation or resistance, and performs a variety of other functions.

There are natural radiation sources, such as our sun and the stars, and artificial radiation sources, such as incandescent and fluorescent lights, heat sources, and lasers. Many optical systems process radiation not manifested as visible light. UV and IR wavelengths or spectral bands are converted by detectors, re-imaged onto vidicons, charge-coupled devices (CCDs), or charge-injected devices (CIDs), and made visible by excited liquid crystal devices (LCDs) or phosphors in cathode ray tubes (CRTs). The electrical output of scanned or staring array detectors is often digitally processed directly for display or transmission. Image processing can modify, enhance, focus, or store images for display viewing, automatic tracking, correlation, and automatic decision-making through artificial intelligence. The preceding is indicative of the close relationship between optics and electronics; as a result of this relationship, the field of electro-optics (EO) has come into being.

The electromagnetic radiation properties of light, such as intensity and spectral emission, can be precisely measured in the optics disciplines of spectroscopy and radiometry. Here, solid-state physics comes into play, since both sources and detectors of radiation are often solid-state devices.

Optics Design

Optical systems designs, perhaps the most widely studied field of optics, deals with the propagation of light. Recent innovations in the optics field have greatly simplified the task of the optical systems designer. Optical systems include such imaging and non-imaging systems as photographic objectives and laser beam expanders. Their performance is specified in terms of how well they transfer object detail into image detail or how well their wavefronts are transferred. Both physical optics (the diffraction characteristics of electromagnetic radiation) and geometrical optics (straight line radiation) are considered in the design of optical systems. Diffraction-limited performance may be the goal of the lens designer, but geometrical aberrations usually set the real limits. In fact, optical designers have been fighting aberrations ever since creation, when God said "Let there be light!" and Lucifer added, "But never in the right places!"

Many optical materials are now available to the optical systems designer, enabling wide spectrum correction. High-speed computers with optical design optimization and analysis programs have dramatically reduced the laborious task of ray tracing, thus yielding vastly improved performance.

Many complex optical systems, such as zoom lenses, would not be feasible without newly developed coatings. These coatings are thin films deposited on optical surfaces that use the wave nature of light (interference) to reduce reflection losses. They can increase mirror reflectance, selectively transmit/reflect radiation (dichroism), and affect polarizing properties.

While optical design and analysis, including atmospheric/environmental EO analysis, and testing of optical components and systems have progressed tremendously in the last few decades, the important phase of fabricating precision optics has changed little.

The Optics Career

Level of education and practical experience will determine the student's starting point in the optics industry. A theoretical knowledge of optics is a marketable skill. In addition, practical experience acquired through laboratory research or part-time or summer employment in an industry in or related to the field of optics is an asset and increases employment opportunities. Education will prepare the student with the theory-base to solve problems in the design, analysis, and testing of real optical products. Not only are math and physics important; the student must have the ability to draw logical conclusions from his efforts and communicate clearly, both verbally and in writing. Computer literacy is also important.

A general knowledge of mechanical mountings and electronic controls, detectors, processors, and displays is also mandatory for an optics professional, as are the environmental effects of storage and operation of materials.

There are many career options for the optics graduate. Some students remain in academia as teachers, receiving financial support through university research grants and graduate assistantships. Supplemental compensation may come from consulting contracts or part-time work with industry. This form of compensation is particularly valuable since it gives the instructor insight to applied theory, which helps to lend realism to the optics classroom.

Generally, students prefer to seek employment in industry. In recent years, however, the U.S. optics industry has undergone significant changes. Predominant photographic product companies like Kodak, Polaroid, and Bell & Howell have been negatively affected by high labor costs and other technical and economic considerations, including a shift of the market to the Far East. Advancements in video technology have virtually eliminated the home movie business. While video cameras need lenses, they cannot be competitively produced in this country. As a result, American companies engaged in optics-related production are undergoing severe stress.

Conflicts around the globe, along with a concern strengthening U.S. defense capabilities have led to an increase in military EO system development. The space program has made an impact in the optics industry as well, as have sophisticated optical systems in the medical and industrial fields.

Where the Action Is

Currently, the aerospace/military optics industry offers the greatest opportunities in optics. This basically domestic, captive market relies primarily on technical performance excellence, while simultaneously maintaining tight cost and schedule restraints. EO systems are being perfected to achieve a state of development beyond "state of the art."

This drive for perfection serves as a constant challenge to the designer to conceive and invent new and better systems. The vast resources of large aerospace companies permit detailed, rigorous designs, analyses, and trade studies of different concepts and approaches that can be very satisfying and challenging to the engineer. However, the time span between a request for proposal (RFP), design of a new system, and submittal of a responsive proposal is generally quite limited, causing high-pressure demands for meeting cost and schedule requirements.

During the RFP process, the customer (usually the military) states a need or desire for a new system. Civil service engineers and scientists interpret these strategic or tactical requirements into specifications that industry will use to design systems which satisfy the needs of the customer.

Since most contracts today are firm fixed price (FFP), not only the design expense, but the cost of manufacturing, assembling, and testing the hardware (and associated software), as well as other indirect costs, must be known and estimated. Delivery schedules must also be prepared. The customer evaluates a number of proposals from different companies and may select only one (perhaps two to maintain competition). Proposals may consist of thousands of pages comprised of accurately and convincingly written statements that are backed up by analyses, quotations, and estimates conveying the company's competency and efficiency at accomplishing future tasks.

Once the proposal is won and the contract is obtained, the company's work starts in earnest. Typical aerospace companies are structured in a matrix fashion: employees are assigned to a functional department and to a specific program. This two boss system is quite natural, since most of us are used to having parents who did not always give us the same signals. Matrix Management provides organizational flexibility: the engineering skills are pooled in the functional departments, and functional management knows the talents of the individuals; program management is program-oriented and knows the design, analysis, and hardware requirements of the specific system.

Functional departments exist only on paper and are comprised of all the engineering talent, including engineers in the mechanical, optical, electronic, EO analysis, structural, environmental, and thermal analysis fields. Program teams are assembled from these skill areas and assignments may last weeks, months, or years. By negotiating skillfully, program management recruits the best engineers for the tasks at hand. The opportunity to draw on the functional pool for the required talent needed for a specified time frame allows the most effective use of resources. Design phases may be relatively short, while the transition into the manufacturing phase may last much longer. The engineers have to support contract activities for selection and qualification of subcontractors and suppliers, write specifications, discuss test methods, explain procedures, and support quality control activities. Domestic and international travel are common.

It will take the new engineer time to become familiar with the way an organization works: both in terms of products and manpower/management. To function effectively, it is important for an engineer to learn the system: How are things done? How was a similar product executed before? What worked? What didn't? What lessons were learned? Who does the engineer go to for help?

Another important consideraton is applying the right measure of effort to the job. Not all designs require the same degree of detailed analysis or stringent performance. Time is money, and an over-designed product is just as bad as an under-designed one: neither will survive competition.

The responsibility for an optical design on a project is a serious obligation. The optical engineer may work alone or as part of a small team. Design reviews are called periodically and designs are critiqued and/or guided in the right direction. Peers and functional management will support the new engineer through the learning process.

How You Fit In

There is no best way to prepare for a career in optics; the field is simply too diverse. The right course of study and preparation depend on individual makeup and interests. These interests will change as the engineer is exposed to a great variety of optics-related problems. New opportunities for solving these problems will occur frequently, and since new discoveries may alter the character of current-day optics, a broad educational background is desirable.

A listing of graduate optics courses and theses from the University of Rochester's Institute of Optics perhaps best reflects the diversity of the optics field. Among these are:

1. Holographic Optical Elements
2. Anamorphic Gradient Index Lens Systems
3. AC Interferometric Refractometry of Transparent Solids
4. Focal Shifts in Truncated Gaussian Beams
5. Diffraction Pattern Analysis as a Method for Surface Roughness Measurements
6. Dynamically Loaded Scratch Tester for Thin Film Adhesion Measurements.

These subjects are not only of academic interest, but also explore underlying principles (cause and effect) that are essential to understanding optics problems and working toward their solutions in the real world.

Just as there is no best way to prepare for a career in optics, there is no best type of person for the optics field. Outgoing, gregarious program managers are required just as are introverted, solitary investigators. In the final analysis, reducing theory to practice and transforming an idea into working hardware is what being an optical engineer is all about.