Guest Editorial

Optical Engineering at AVCO Everett Research Laboratory

I. ITZKAN

Since the work and scope of Avco Everett Research Laboratory, Inc. (AERL) is not familiar to many optical engineers, I thought I would use the opportunity of this guest editorial to review the history of the Laboratory and its present activities as they relate to optics.

AERL was founded in 1955 by A. R. Kantrowitz, who is now Chairman and Chief Executive Officer. The present president is H. E. Petschek. The first problem attacked and solved was the excessive heating of missiles and space vehicles reentering the earth's atmosphere, thereby helping the U.S. to enter the space age. Since then, the Laboratory interests have evolved from reentry technology to remote sensing, magnetohydrodynamic power generators, medical research, high power lasers, tunable lasers, and isotope separation techniques. Optics has been an integral part of the Laboratory from the beginning and continues to play two major roles in the Laboratory's operations; as a diagnostic tool in most experiments, and as a discipline within which new advances are to be made.

While Avco Everett's early work provided a basic understanding of the physical environment to be faced by reentry vehicles, it quickly became apparent that measurements of actual missile reentries would be extremely valuable for comparison with Laboratory research.

In recognition of this need, early in 1958 Avco Everett took part in an effort to make quantitative measurements of the radiation from the reentry of a Jupiter missile. A 6-man AERL team participated in the initial reentry measurements experiment aboard the destroyer U.S.S. Stickell during Jupiter Test AM-5 on the Atlantic Missile Range on 18 May 1958. The experimental equipment included a nest of four

Leica cameras and a ballistic camera — used to obtain trajectory information essential in correlating events with reentry vehicle altitude. A 16-mm cine camera was hand-held to track the reentry vehicle and measure integrated radiant intensity in the visible wavelengths. A six-barrel radiometer and a two-barrel radiometer — each with an 8-mm boresight camera — were used to measure radiant intensity in discrete spectral regions within the visible part of the spectrum.

Today's field measurements offer the advantage of studying physical phenomena — full-scale — by optical and radiometric techniques from a remote platform. Figure 1 is a photograph of one of two specially instrumented KC-135 aircraft which operate from Patrick AFB, Cocoa Beach, Florida, and serve as the airborne platforms for the SAMSO Terminal Radiation Program (TRAP). Meanwhile, a major ground-based platform is located on Mt. Haleakala, Maui, Hawaii, where the Laboratory provides technical direction and systems engineering for the ARPA Maui Observation Station (AMOS). Figure 2 is a photograph of the 60" telescope and Figure 3 shows the twin 48" telescopes — which are installed at this station. Such activities have prompted the development of electro-optical equipment required for airborne and ground-based remote sensing systems for related activities such as weather data gathering, pollution monitoring, and reentry systems monitoring. This experience has included the use of multichannel radiometers and spectrometers, and visible and infrared wavelength imaging systems.

In the mid 1960s, laboratory work by D. Leonard and R. Caristi led to the development of AERL's first commercial product, the 3371 Å pulsed nitrogen laser, which provided

Figure 1. Trap-1 aircraft in flight.

Figure 2. AMOS 60" telescope.

the scientific community with its first coherent ultraviolet source. Using this source as a pump, it is now possible to generate tunable coherent radiation from 800 Å in the ultraviolet to 20μ and beyond in the infrared. The visible portion of the spectrum is obtained by using the nitrogen laser to pump tunable dye lasers optically. For this use we have manufactured and marketed a packaged dye cell unit, which, combined with the laser, can be tuned over overlapping bands to cover the whole visible spectrum.

The near UV is obtained by doubling the tunable visible dye laser in a nonlinear crystal. The far UV is obtained by summing three photons, two from one dye laser, and one from another dye laser in a cell containing metallic vapor. Both dye lasers can be pumped by the same N₂ laser. The infrared is obtained by using suitable difference frequencies of two dye lasers in metallic vapor cells. The pulse repetition rate of the nitrogen laser has recently been increased to 500 pulses per second. A flowing dye cell attachment for it has

Figure 3. AMOS twin 48" telescopes.

been developed; the result is a higher average tunable laser output power and better output beam quality.

Another application of the pulsed N₂ laser is laser Raman spectroscopy. The Raman effect has been an analytical tool in laboratories worldwide for many years. However, high-intensity visible and ultraviolet laser sources had to be perfected before relatively weak Raman scattering could be practical for remote pollution monitoring in atmospheric effluents. Currently, Avco Everett is seriously investigating the measurement of aircraft gas turbine exhaust emissions with a laser Raman spectrometer. A first-generation laser Raman spectrometer incorporating a nitrogen laser as the prime source of radiation has been designed and constructed for field measurements. Figure 4 is an illustration of this spectrometer located in a van, measuring the composition and temperature of a jet engine exhaust.

First attempts to analyze the exhaust products from a gas turbine combustor were successful at high temperature levels. However, at low fuel-to-air ratios, a laser-induced background appears. Its characteristics suggest fluorescence induced by the UV laser source in polynuclear aromatic hydrocarbons. Further study is planned to better understand the background problem.

The Laboratory is presently developing a new isotope separation technique believed to have commercial

Figure 4. Schematic of remote Raman spectrometer measuring aircraft engine exhaust.

applicability in uranium enrichment — an important step in the preparation of uranium for use as a fuel in nuclear electric power plants. It involves separating the uranium isotopes U-235 and U-238 so as to obtain a product enriched in U-235. According to AEC and nuclear industry projections, some 20 percent of the nation's electricity will be produced by nuclear power plants by the end of 1980. It was in response to the related demand for enrichment services that Jersey Nuclear-Avco Isotopes Inc. was formed in 1972 by Exxon-Nuclear Corporation and Avco Corporation to continue development of techniques which involves the application of laser technology, and could result in a significant reduction in fuel costs for nuclear power plants. Lasers are desirable as light sources in this application by virtue of the large intensities and narrow bandwidths available. However, the exact wavelength requirement for a light source for this application requires an accurately tuned laser. Presently available dye lasers have bandwidths as narrow as atomic linewidths and may be tuned across the whole visible spectrum. The Dial-a-Line lasers, manufactured and sold by Avco Everett, may be used as a source of these photons with minor modifications. This can be accomplished by using a conventional etalon filter to obtain a narrow bandwidth.

One possible working material is metallic uranium which is known to exhibit at least one line which lends itself to this process. This line, at $5027 \text{ \AA}$, has an isotope shift of $0.103 \text{ \AA}$ between U-235 and U-238. The bandwidth of about $0.01 \text{ \AA}$ achievable by the dye laser is much smaller than this isotope shift and hence, the selective excitation of U-235 is possible.

The gasdynamic laser (GDL), a thermally pumped device, was invented and developed at the Laboratory in 1965 by a team led by E. T. Gerry. Hot nitrogen and carbon dioxide gas flowing through an array of small-throat supersonic nozzles, produces a population inversion from the equilibrium gas mixture by differential vibrational relaxation. This gas mixture can be produced by combustion of a suitable fuel — by addition of heat to the gas, or by electrical excitation. An optical cavity, usually an unstable resonator mounted at opposite ends of the supersonic channel, extracts the full available power from the gas medium. The beam is then

Figure 5. Mark V gasdynamic laser.

Figure 6. Interferogram of flow through a gasdynamic laser nozzle.

focused out through an aperture in an aerodynamic window. Figure 5 is a photograph of the Mark V. This GDL was the first laser to deliver 135 kilowatts — many times the power output of any other CW CO_2 laser of its time.

Advances in optical components and diagnostic techniques have been an integral phase of high-power laser development at Avco Everett. Since the attainment of a diffraction-limited output beam was crucial, we teamed with Hughes Research Laboratories to develop unstable resonator optical cavities for high power lasers. This technology remains in our present-day gasdynamic and electric discharge CO_2 lasers, and in our chemical lasers. Further, we have set up interferometers to diagnose the optical quality of the gaseous medium — a necessity for good beam quality. Figure 6 is an interferogram of flow through a GDL nozzle taken

with an Avco 3-nanosecond pulsed Neon laser at 5401 Å. Also, when it became evident in the development of high-power lasers that mirrors with glass surfaces could not withstand the absorbed heat, we pioneered in the development of metal mirrors which could be water-cooled.

An outgrowth of the GDL, the electric discharge laser (EDL) accomplishes a population inversion by pumping carbon dioxide and nitrogen molecules to the upper state via electron collisions. As in the GDL, waste heat is removed from the cavity by flow, but unlike the GDL, the EDL can be a closed-cycle circulation system with heat exchangers and blowers. To eliminate the problem of arcing at high pressure, the ionizer-sustainer laser was developed. By separating the functions of ionizing the gas and sustaining the discharge, this technique eliminates the instabilities which occur when self-regeneration is used to maintain the level of ionization. In the AERL devices, the separate ionization source is a high-energy electron beam, and in its pulsed version, has produced 2 kilojoules in a 20-microsecond pulse. Figure 7

Figure 7. Two thousand joule electric discharge pulsed CO_2 laser.

shows an EDL in action. The beam is directed across the room by a focusing mirror located just outside the picture. Whenever it encounters a dust particle it causes air breakdown, creating the string of sparks seen in the photograph. The successful use of an e-beam ionizer for EDL's was pioneered and developed by a team led by J. Daugherty at AERL.

We are beginning to see industry's acceptance of the high power laser metalworking first reported by the Laboratory in 1970. Experimental studies of welding, cutting, and surface heat treating with a continuous-wave electric industrial CO_2 laser have been conducted at output power levels up to 16 kW. This CW version of the EDL emits radiation at 10.6 microns; the beam's focal spot diameter is 0.28" with an f-7 telescope. The laser uses a rapid flow of gas to remove the waste heat from the optical cavity. In turn, a water-cooled heat exchanger removes the heat from the gas, whereupon the gas is recirculated through the optical cavity. The closed cycle gas flow system — including blowers, heat exchangers, and laser cavity optics — is contained in a rugged steel box, maintained at approximately 0.1 atmosphere. The first Avco Laser Metalworker — Model HPL-10 — which operates typically in the 10-15 kW range, was delivered to Caterpillar Tractor Co. in 1972. The second HPL-10, held in the

Figure 8. 16-kilowatt continuous CO_2 laser.

Laboratory for materials testing studies and customer demonstration, is leading to the discovery of many new applications. In Figure 8, it is shown welding $\frac{1}{2}$ "-thick stainless steel plate at 25 inches per minute, using a standard milling machine for work traverse.

The beam is directed down at the work through the output telescope in the foreground. The metal dome in the background to left houses the electron beam generator for the cavity. A flexible duct vents the work region which is shielded by plexiglas panels. An alternate work station is shown in the background, at far right.

This laser can process complicated shapes and multiple parts without applying force to the work. This dexterity is facilitated by programmed direction and redirection of the beam. Welding, cutting, and hardening the surface of a complex piece in a continuous on-line operation have been demonstrated. The high-power beam can be directed sequentially to separate work stations, where jobs have queued up for the single laser source. Alternatively the high-power beam can be split into a number of low-power beams directed simultaneously and independently operating work stations.

In 1970, recognizing that the role of Optics within the Laboratory had achieved full disciplinary status, the Optics research committee was formed, to take its place alongside the Laboratory's other major disciplinary committees, Atomic Physics, Aerophysics, and Plasma Physics. Among the advances stimulated by this committee are the improvement in the ability of large telescopes to obtain diffraction-limited information in the presence of a turbulent atmosphere by means of speckle interferometry, laser beam propagation and laser radar studies. The five Avco papers presented in this issue are samples of this work.

In the realm of Raman spectroscopy, "Remote Probing of a Volume at Finite Conjugates," by J. L. Munroe discusses the isotropically scattered signal received by an optical system when a remote volume is irradiated; he shows that while the calculation of such a signal is usually difficult, that for a rectangular aperture, these calculations are concise and suited to ordinary numerical techniques.

The radiation at the output aperture of an unstable resonator consists of a circular or rectangular annular beam with predictable intensity and phase distribution. In "Useful

Beam Quality Design Curves for Unstable Resonators," M. M. Weiner describes the various far-field beam parameters as a function of the intensity and phase distribution at the output aperture. The results are of great utility to the designer of laser optics.

G. M. Daniels, in "A Computer Program for Atmospheric Infrared Transmission and Background Calculations," introduces a program which calculates atmospheric path transmission for radiation in the spectral region of 8-25 microns. After reviewing atmospheric absorption properties and atmospheric band model transmission calculations, he outlines the calculation procedures. Comparison of calculated predictions and several data samples shows good agreement.

"An Airborne Telescope-Camera System for High-Resolution Reentry Vehicle Photography," by G. M. Daniels and G. L. Dryden discusses an airborne telescope-camera system designed for high-speed, high-spatial-resolution photography of space vehicles during reentry. Limits on spatial resolution in the system's field are identified, and the system's theoretical performance is analyzed in terms of modulation transfer functions. The predicted resolutions — 2.0–2.5 arc sec — approximates measured field performance.

"Improved Acquisition of Targets Seen Against the Daylight Sky" by G. R. Abell and G. Phillippou details the results of using closed-circuit TV for enhancing the effective contrast of weak targets against the sky in daylight, thus facilitating their acquisition. The acquisition performance of direct human vision is presented as a standard of comparison and as the final sensor in a television-equipped acquisition system. The attainable performance of such a system is described mathematically, and additional performance limitations due to real imperfect system components are identified. Results achieved with an experimental system are presented.

The five Avco papers presented in this issue are only the tip of the iceberg. We are glad to have had the opportunity of a special issue of *Optical Engineering* to be able to communicate some of our results to the rest of the optical engineering community.

I would like to thank S. A. Rodrick for help in the preparation of this editorial and M. R. Massinger for help with all the phases of assembling and editing this issue.

CALL FOR PAPERS

Seminar in Depth

TECHNOLOGICAL ADVANCES IN MICRO AND SUB-MICRO PHOTOFABRICATION IMAGERY

AUGUST 21-23, 1974

GENERAL CO-CHAIRMEN

J. M. Graf, Supervisor, Materials Processing Laboratories, Aerojet Electro-Systems Company
William Converse, Signetics Corporation

The primary purpose of this seminar is to review the history and the current and advanced state-of-the-art as applied to photofabrication technology, with emphasis on Projection Printers, Proximity Printers, Step-and-repeat Photo Printers, and High-resolution Reduction Cameras as used in micro and sub-micro imagery. Additionally, it is hoped that a meaningful dialogue can be initiated between producers of equipment and product and users.

Original and tutorial papers, as well as brief reports, addressing critical problem areas are invited on, but not limited to, any of the areas listed below:

History of projection printers • History of step-and-repeat photo printers • Evolution of high-resolution cameras • Optics for high-resolution imagery • High-density array image recording • High-resolution projection printing • High-resolution proximity printing • Exposure of highly reflective substrates (metallic) • Reduction systems—microphotographic • Accuracy—step-and-repeat photo printers • Large-area printing • Stabilization of high-resolution recording equipment (thermal and mechanical) • Photo-mask fabrication • Photo-mask multi-level printing • Selecting a photo-mask (see-through, etc.) • Photo-mask terminology • Surface flatness of photo-masks • Intrinsic, extrinsic detector configuration • Step-and-repeat resist imaging • Photo resist • Electro forming.

ABSTRACTS of not less than 100 words are due by May 7th, 1974.

COMPLETE MANUSCRIPTS are due by July 27, 1974.

PRELIMINARY SCHEDULE OF INVITED PAPERS:

NEW DEVELOPMENTS IN PHOTO RESIST APPLICATIONS

S. Harrell, Cobilt Company, A Division of Computer Vision

PROJECTION PRINTING

R. Frinnela, Hughes Aircraft Company

HARD SURFACE PLATES

W. Converse, Signetics Corporation

PHOTO MASK TECHNOLOGY

J. MacDonald, Align-Rite Corporation

PLASMA DRY-ETCHING

J. Mitzel, Tegal Corporation

PLASMA STRIPPING

J. Mitzel, Tegal Corporation

SOCIETY OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS

P.O. BOX 288, REDONDO BEACH, CALIF. 90277 • (213) 378-1216