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OPTICS AND PHOTONICS RESEARCH IN THE LASERS, OPTICS AND REMOTE SENSING DEPARTMENT AT SANDIA NATIONAL LABORATORIES

K. Simmons-Potter and D. C. Meister

Sandia National Laboratories

Albuquerque, NM 87185-1423
phone: (505) 844-1271, fax: (505) 844-5459
e-mail: kspotte@sandia.gov

ABSTRACT

Photonic system and device technologies have claimed a significant share of the current high-tech market. In particular, laser systems and optical devices impact a broad range of technological areas including telecommunications, optical computing, optical data storage, integrated photonics, remote environmental sensing and biomedical applications. Below we present an overview of photonics research being conducted within the Lasers, Optics and Remote Sensing department of the Physical and Chemical Sciences Center at Sandia National Laboratories. Recent results in the fields of photosensitive materials and devices, binary optics device applications, wavelength generation using optical parametric oscillators, and remote sensing are highlighted.

INTRODUCTION

Current state-of-the-art technology is driven, in large part, by advances in both the design and implementation of complex optical systems. Applications, ranging from optical telecommunications (in which gigabits of encoded optical data are transmitted down hair's-width glass fibers) to orbiting satellite systems, rely heavily on optical materials, optical systems and lasers. In the Lasers, Optics and Remote Sensing department of the Physical and Chemical Sciences Center of Sandia National Laboratories we perform leading research in a number of enabling optical technologies. In the following text, five specific research areas will be addressed: photosensitive optical waveguides, binary optics technology, laser wavelength generation using optical parametric processes, remote sensing in turbid environments and remote chemical sensing.

PHOTOSENSITIVE OPTICAL WAVEGUIDES

Photosensitive (PS) materials exhibit a permanent refractive index change when exposed to optical radiation. Thus, it is possible to optically imprint detailed refractive index structures into a photosensitive film by simply exposing the material to the proper wavelength of laser light. Such structures have the ability to guide, reflect, and re-route light traveling within the plane of the film. Therefore, the use of PS materials allows the fabrication of a broad range of complex integrable optical devices using a single, optical, direct-write process (Fig. 1). Potential applications areas include waveguide devices, integrated optical interconnects, diffractive, refractive and reflective optical elements, sensors, and optical data storage.

We have successfully produced large refractive index modulations ($\Delta n \sim 10^{-3}$) in germanosilicate thin-film waveguides by exposure to UV radiation [1]. The films were fabricated using a novel reactive-atmosphere, RF-sputtering technique which represents an innovation in the production of these PS materials. Currently our films demonstrate the

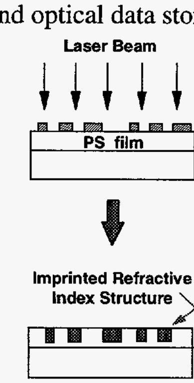

Figure 1: Laser imprinted optical device archetecture.

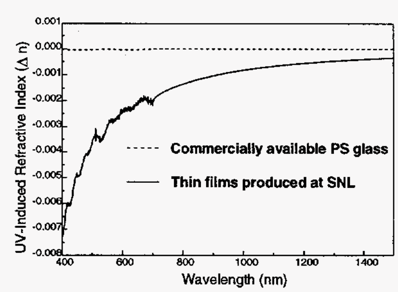

Figure 2: SNL films demonstrate the largest reported as-deposited index modulation in PS materials.

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largest reported as-deposited photosensitive response across the visible and well into the infra-red portion of the optical spectrum which is > 100x greater than that typically observed in commercially available materials (Fig. 2). Our technique offers in-situ control and long-term stability of the glass photosensitivity [2-3]. In addition, by manipulating deposition parameters during film fabrication, we have established the ability to tune the photosensitive response of our films [4]. Using this approach we find that two regimes of photosensitive behavior can be accessed within which both the magnitude and sign of the induced refractive index modulation can be tailored. Thus, through direct control of material structure, dramatically different device responses can be obtained.

BINARY OPTICS

The phase of an optical beam is a parameter which can be evaluated to perform surface metrology of optics, thin films and mechanical components and to characterize the quality of laser beams. Phase measurements are commonly used, for example, in fluid mechanics to infer density distributions and in laser optics to analyze laser beam propagation characteristics. We have developed a new type of wavefront sensor which is compact and versatile and which enables detailed measurement of the phase of optical beams [5-6]. Our technique utilizes microphotolithographic etch processing to fabricate multiplexed arrays of microlenslets. These lenslets focus incoming light to a series of focal spots whose location is dependent upon the aberration intrinsic to the impinging light. Thus, by analyzing the focal spot locations resulting form a test beam and comparing this information to the focal spot locations corresponding to an incident unaberrated or "perfect" beam, we can determine phase information about the test beam and use this to reconstruct its wavefront. Figure 3 shows a two-tier lens system and highlights the advantage of our lens multiplexing technique. Light from the entire aperture is focused to a spot in the center of the field while light from each quadrant is split and focused to the center of each region. The multi-tiered sensor, by using light from all portions of the aperture, uses the structure of the light itself on the focal plane to form the appropriate information necessary for efficient wavefront sensing.

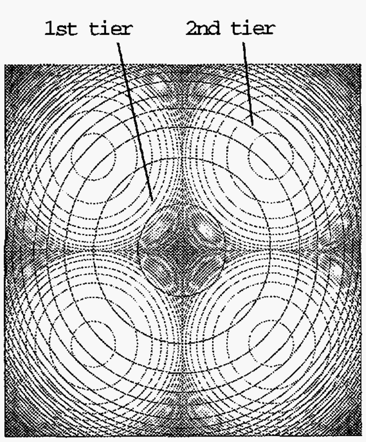

Figure 3: Two-tier lens system.

LASER WAVELENGTH GENERATION

Lasers are rapidly entering the commercial and even consumer market as evidenced by the abundance of check-out counter scanners and compact disk players. As the range of available laser wavelengths increases new opportunities arise for commercial devices, such as high density optical disks based on blue and ultraviolet sources and chemical sensors based on infrared sources. Nonlinear optical devices, such as Optical Parametric Oscillators (OPO's), can greatly expand the range of available wavelengths and, as such, represent an important technolgy in future optical commercial devices.

An optical parametric oscillator (OPO) is an optical device pumped by a laser to produce two wavelengths which are different from that of the pump laser (Fig. 4). OPOs can be used to shift the wavelength of fixed frequency lasers to a specific desired wavelength or to generate tunable light. The new waves are usually labelled the signal and idler. OPO's can produce coherent optical radiation tunable from the ultraviolet to the far infrared.

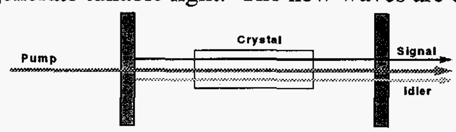

Figure 4: Typical optical parametric oscillator

We have built a laboratory capability for constructing and characterizing OPOs and have developed state-of-the-art computer models for nanosecond duration pulsed OPOs [7-8]. Our models include the effects of light diffraction of the interacting optical beams in the OPO cavity, the effects of beam walkoff in the nonlinear crystal responsible for producing the shifted wavelengths, and the effects of strong energy exchange among the beams in the cavity. We are currently using our computer model to explore new, compact OPO designs which demonstrate improved performance over conventional designs. In particular, we are trying to obtain high efficiency and acceptable beam quality from OPOs that may be pumped by solid state lasers.

REMOTE SENSING IN TURBID ENVIRONMENTS

Visualization of objects and internal structure obscured by pervasive scattering and nearly opaque overlayers in turbid media is fundamental to solving many problems of current technical interest in the areas of medical imaging (optical biopsy of tissue), remote sensing (oceanographic and atmospheric lidar), and nondestructive metrology of buried interfaces. The primary obstacle to the implementation of conventional light-based imaging methods in low-visibility fog-like environments is the presence of scattering which can mask the direct line-of-sight and degrade underlying image information. Ballistic imaging is a technique which seeks to isolate image information from the adverse effects of scattering using a fast time-gate superimposed on the transmitted or reflected light signature to preferentially detect so-called ballistic (minimally scattered) photons which maintain a high degree of coherence.

We have developed a new quasi-ballistic imaging technique capable of detecting and spatially resolving reflective images from specular, extended, and diffuse objects through coastal seawater and flame environments with overall scattering attenuations approaching ten optical densities (Fig. 5). Preliminary

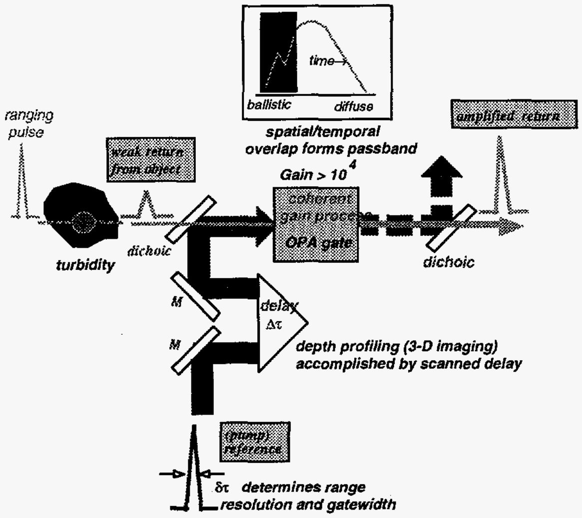

Figure 5: Operational concept: weak return light is overlapped with time-delayed pump pulse in a nonlinear optical crystal (OPA) to give an amplified image.

benchmark experiments have been performed to reconstruct images with feature sizes of 65 microns in background optical (scattering) attenuations exceeding twelve orders of magnitude [9-10].

REMOTE CHEMICAL SENSING

The ability to detect and identify effluents from mining, refining, reprocessing or enriching of nuclear materials is of critical importance to world-wide security. We are participating in a multi-lab effort to address such issues through an agile remote chemical sensing scheme entitled CALIOPE (Chemical Analysis by Laser Interrogation of Proliferation Effluents) [11]. Our efforts have resulted in the development of a unique multispectral ultraviolet (UV) remote sensing system capable of identifying chemical species at distances greater than 1 km (Fig. 6). Major project activities have

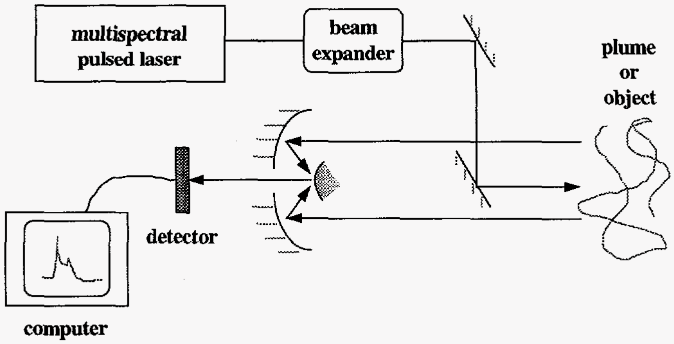

Figure 6: Mulitspectral UV remote sensing system.

included research to identify and evaluate relevant sources and UV signatures for gases, liquids and solids, to produce modeling and system evaluation methods and to develop remote sensing field test capabilities. Our remote sensing capability has integrated efforts in the development of broadly tunable solid-state UV sources, in the acquisition and compilation of a spectroscopic database of fluorescence signatures for materials and backgrounds, and in the design of computationally intelligent analysis algorithms.

CONCLUSIONS

Sandia National Laboratories is a multidisciplinary research institute whose work impacts both the private sector and our core missions in the national interest. Research in the Lasers, Optics and Remote Sensing Department, as outlined above, has wide range implications in the development of new technologies which address our continuing commitment to our DOE mission goals of stockpile stewardship and energy and environment (including waste remediation) efforts. In addition advances made in the fields of optical materials, laser design and remote sensing have demonstrated significant potential for commercialization.

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11. Contact P. Hargis, Sandia National Laboratories, Albuquerque, NM, 87185-1423, (pjhargi@sandia.gov).

BIOGRAPHIES

Kelly Simmons-Potter is a Senior Member of the Technical Staff at Sandia National Laboratories. She received her Ph.D. from the Optical Sciences Center at the University of Arizona in 1994.

Dorothy Meister is a Staff Technical Associate at Sandia National Laboratories. She has worked in the feild of lasers and optics at Sandia for 13 years.