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# OPTICAL COMPUTERS AND SPACE TECHNOLOGY

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## Abstract:

The rapidly increasing demand for greater speed and efficiency on the information superhighway requires significant improvements over conventional electronic logic circuits. Optical interconnections and optical integrated circuits are strong candidates to provide the way out of the extreme limitations imposed on the growth of speed and complexity of nowadays computations by the conventional electronic logic circuits. The new optical technology has increased the demand for high quality optical materials. NASA's recent involvement in processing optical materials in space has demonstrated that a new and unique class of high quality optical materials are processible in a microgravity environment. Microgravity processing can induce improved orders in these materials and could have a significant impact on the development of optical computers. We will discuss NASA's role in processing these materials and report on some of the associated nonlinear optical properties which are quite useful for optical computers technology.

Introduction:

Optical information processing is experiencing a renaissance. This revival is due to a combination of the growing recognition of the fundamental limitations of digital electronic integrated circuits and the recent developments made in the fields of optical materials, optical fibers, nonlinear optics, and optical processing.

Optical interconnections and optical integrated circuits are sought to provide the answer to digital electronic limitations. Optical computing systems can provide broader bandwidths; hence, many independent channels could be exploited for demanding computations. Optical computing is capable of communicating several channels in parallel without interference or crosstalk and free from electrical short circuits. Such computers may be compact in size, lightweight and inexpensive. Optical interconnections offer the combination of large conductor and large fan-out with minimum loss in transmission. Fan- out is the number of signals driven simultaneously by one signal[1]. Bandwidths of gigabits and fan-out of up to 100 loads from a single fiber are feasible.

Recently, an optoelectronic 3-D system, which proved the viability of 3-D optical computers has been developed by Morozov et al[2] . Scholl[3] has described an architecture in corroborating the advantages of both digital and optical image processing. Krasilenko et al. [4] have examined an approach to design an all-optical universal integrated optical logical elements for digital optical systems of data processing and transmission. Gao et al.[5] have reported the dynamic memory function of a hybrid bistable system with long-delayed feedback. N. Q. Ngo et al.[6] have proposed a highaccuracy fiber-optic array processor based on the algorithm of digital multiplication by analog convolution. Guibert et al.[7] have designed an on-board optical joint transform correlator. Their system performed real-time and on -board recognition tasks, such as road sign recognition.

OPTICAL MATERIALS AND NASA' S ROLE:

In the recent years there has been tremendous interest in the field of nonlinear optics (NLO) and optical materials. Optical devices such as optical switching , optical communication, and optical computing all require devices containing materials that possess large nonlinear optical responses. NASA has at least two main interests in NLO research. One interest is that NLO materials could be of use for optical communications with satellites deployed in space. The other area is that NLO materials grown in a microgravity environment could benefit from the minimization of the gravitational force. There is considerable potential that microgravity studies of these materials could enable their properties to be significantly optimized. Eventually, the study of microgravity processing of NLO materials may lead to devices with superior properties to those currently in use.

The processing of optical materials by NASA in space was demonstrated by the deposition of physical vapor transport films in microgravity of copper phthalocyanine (CuPc) material. This experiment was developed by the 3M company. Analyses on these films revealed that microgravity grown films were more highly uniaxially oriented than Earth-grown films, and the films consisted prominently of crystalline domains of a previously unknown polymorphic form of CuPc (Fig. 1).

One promising new class of NLO materials, polydiacetylenes (PDAMNA), has been synthesized recently in our laboratory[8,9]. They were found to be highly conjugated polymers and exhibited a very large optical nonlinearities with fast response times( less than 120 fs). Good quality photodeposited films of PDAMNA, for integrated optical circuits, have been produced. These films are obtained by a photodeposition technique on an optical window using UV light. Efforts are in progress to process PDAMNA films in space to improve their quality even further. The ground-based amorphous films possess superior optical quality (i.e. , greater homogeneity, fewer defects) than those generally obtained via solid-state polymerization. Electron beam diffraction studies indicate no crystal structure. Hence there are no grain boundaries or other crystal defects that can lower the optical quality and cause light scattering.

Recent investigations of the effect of the unit gravity force on the optical quality of polydiacetylene films were performed by changing the optical window orientation with respect to the gravity downward direction. The orientation of the optical window is defined by the direction of its unit vector normal to the surface. Three experiments were performed. In the first one the chamber window was pointing upward and the UV-lamp was on the top. In the second experiment the window was pointing downward and the UV-lamp was underneath it. In the third experiment the window was pointing sideways (Figures 2 a,b,c respectively). The UV light was made to shine for an equal interval of time of 20 hours in each experiment. Through the films obtained from these experiments, waveguiding was achieved by the end-fire coupling technique using a He-Ne laser at 632.8 nm. The scattering from the three films was recorded and digitized by a CCD camera as shown in Figures 2d,e,and f. These scattering data were interpreted based on the principle of convection which causes clusters formation. These clusters are embedded into these films and act as a scattering centers. It is well known that convection is a unit gravity effect. The reduction of convection in a microgravity environment will lead to elimination of clusters and consequently higher quality films.

EXPERIMENTAL RESULTS AND THEIR POTENTIAL USE FOR OPTICAL COMPUTING:

Optical spatial light modulators (OSLMs) are devices which spatially modulate the intensity, phase, or polarization of a light beam in response to optical or electronic input. Modulators are important class of devices for optical computing and allow looping and cascading of devices. These devices are also useful for synchronization and buffering. Some of these devices also have long-term memory and will be of good use for data storage. We will discuss a few of the nonlinear results which have an impact on the signal processing for optical computing:

1. Optical holography is useful for building flexible diffraction gratings. Holographic interconnection devices are capable of establishing one to many or many-to-one interconnections. High-speed operation of optical computers and imaging processors can depend on holographic techniques for interconnections. Holograms can outperform state - of -the art electronic interconnections in density, power, and speed. However, the cost of installing such a system is still high.

The nonlinear technique of Four Wave Mixing (FWM) demonstrates an efficient way of real time holography for optical pattern recognition systems. It was demonstrated in our laboratory that a high fidelity phase conjugate signal ( Fig. 3) from a nonlinear mirror using degenerate four wave mixing was obtained from boric acid glass doped with disodium fluorescein. A large nonlinearity ( $\chi^{(3)} \sim 1$ esu ) at low laser power is measured using a cw $Ar^+$ laser at 488 nm.

2. Bistable devices are the unit blocks of logic gates which are analogous to electronic transistors. Optical bistability requires a nonlinear medium and optical feedback. Feedback is either external where the medium is placed inside a Fabry-Perot etalon, or it is internal where optically induced changes in the medium directly affect its interaction with the incident beam. Internal optical bistability was recorded in our laboratory in metal-free phthalocyanine (Fig. 4).

3. A miniature size optical integrated circuit of polydiactylene was demonstrated using a focused and pre-programmed UV beam from an $Ar^+$ laser at 366 nm. The width of the circuit is controlled by the beam diameter on the substrate window of the chamber and the thickness of the circuit is controlled by the intensity of the beam and the scanning speed or translation rate. PDAMNA material , as mentioned earlier, has a fast optical response time of less than 120 fs. The fabrication of a fast optical Mach-Zhender interferometer switch made of this material is now in progress.

CONCLUSION:

Microgravity research on processing materials opens a great opportunity for the generation of a new and unique class of materials with enhanced optical properties. These materials are strongly believed to be quite promising for the manufacture of future optical computing integrated circuits and optical communication.

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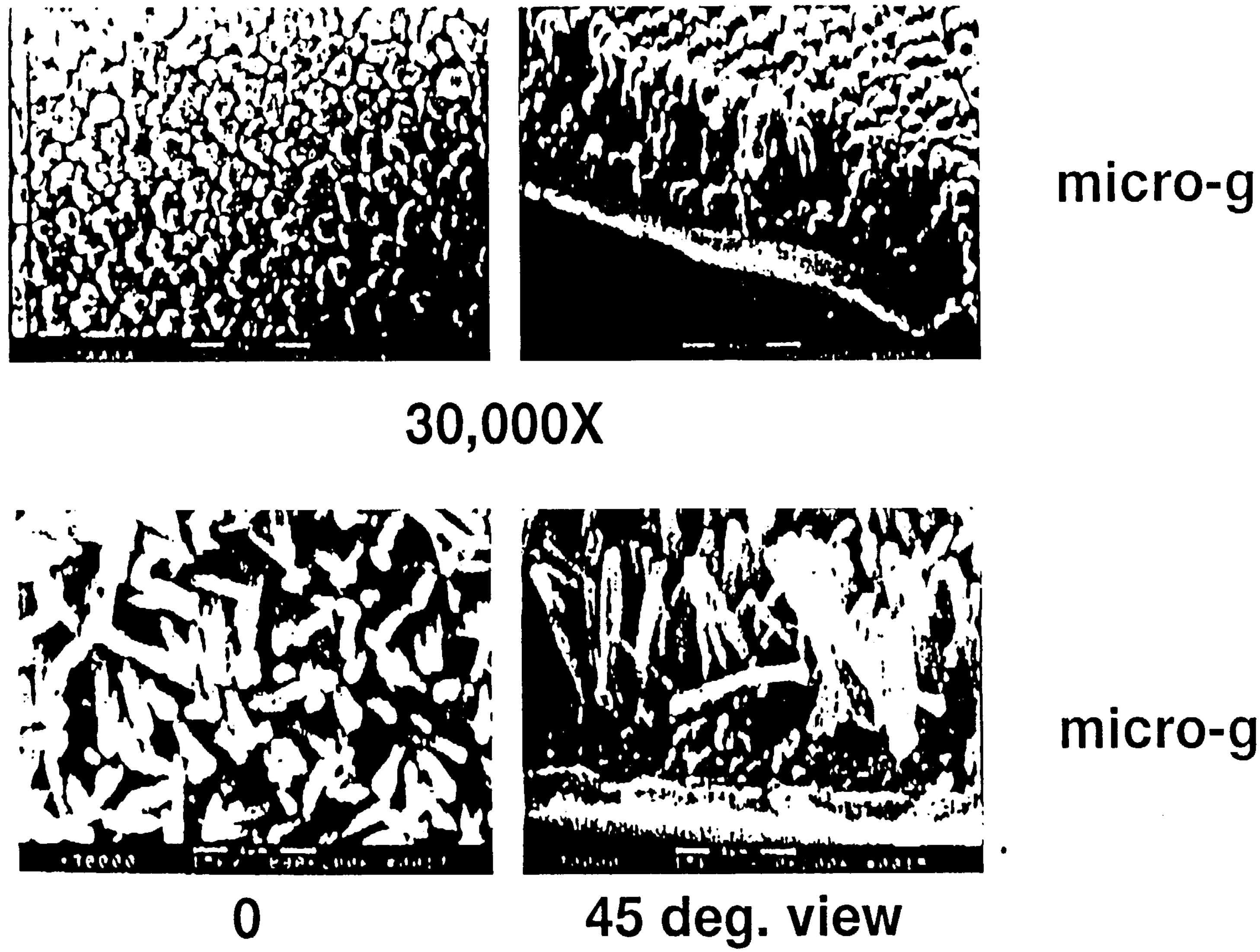


Figure 1. This figure compares scanning electron micrographs of 1–μm thick films of copper phthalocyanine deposited by physical vapor transport in the 3M PVTOS flight (STS–20) and ground control experiments. In microgravity the film's microstructure is very dense compared to that produced in unit gravity in the presence of convection. This difference in microstructure has a significant affect on the macroscopic film optical properties.

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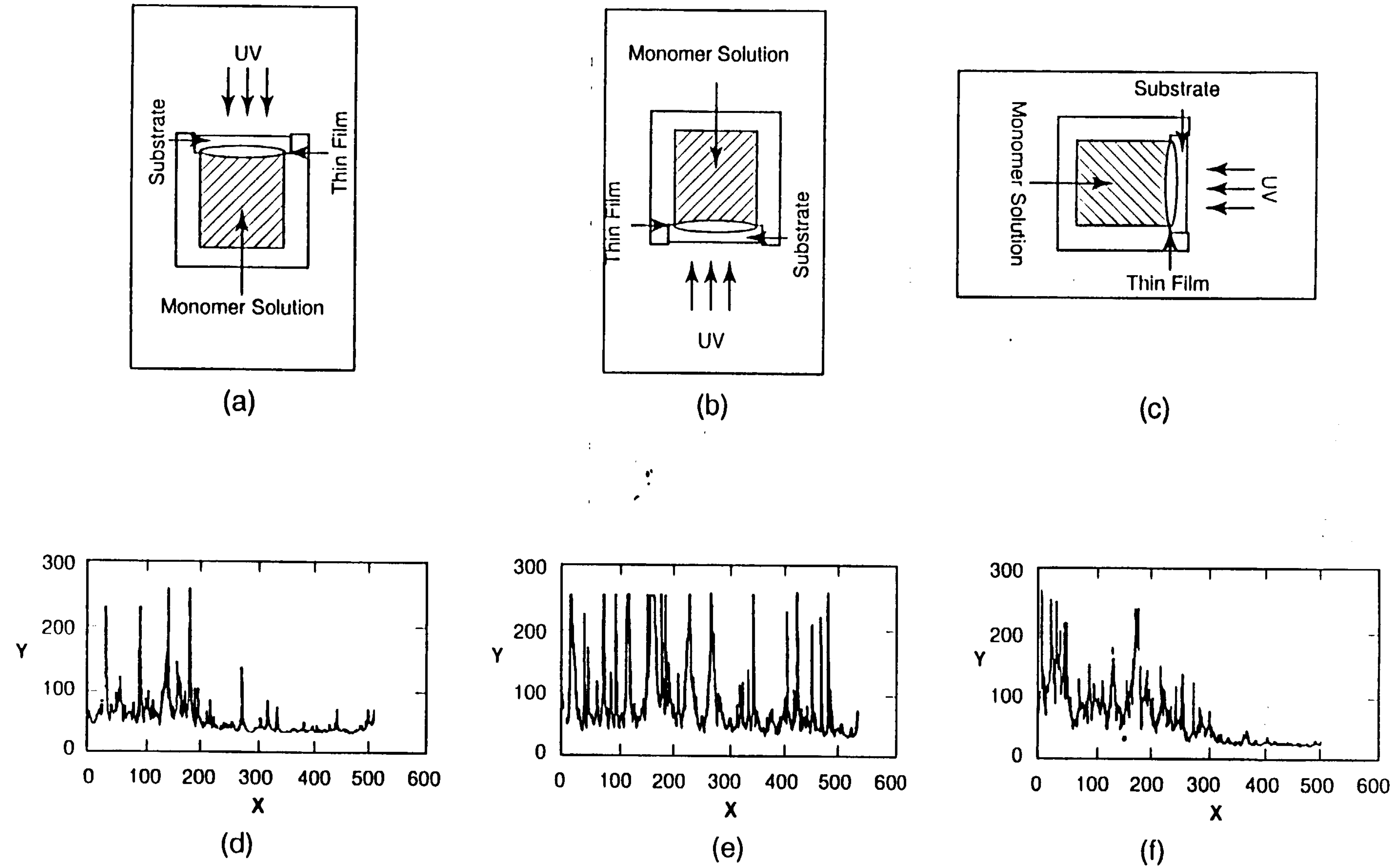


Figure 2. (a) The upward vertical orientation of the optical window (b) The downward vertical orientation (c) The sideways orientation (d) The wave guiding scattering from film in orientation (a) (e) The wave guiding scattering from film in orientation (b) (f) The wave guiding scattering from film in orientation (c)

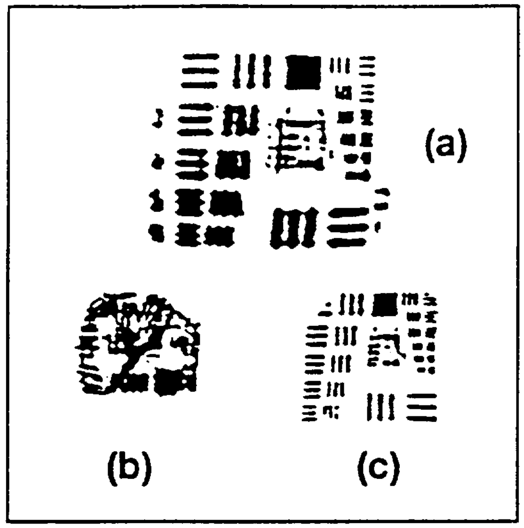


Figure 3. (a) The input signal of the U.S. Air Force chart on the probe beam.
(b) The image, distorted by the optical components, reflected by a regular mirror in place of the sample.
(c) The signal, free from distortion, obtained from the phase conjugate mirror.

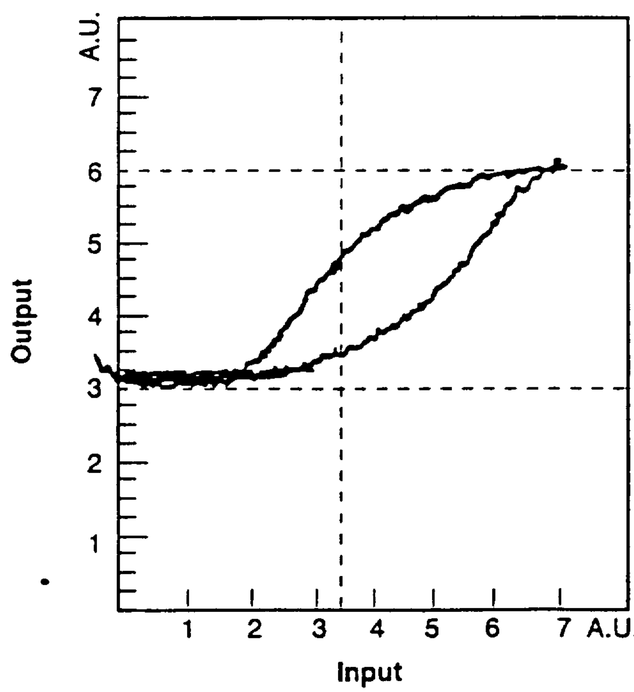


Figure 4. The optical bistability of metal-free phthalocyanine film of 833 nm thickness using chopped He-Ne laser at 632.8 nm and frequency 245 Hz.

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