

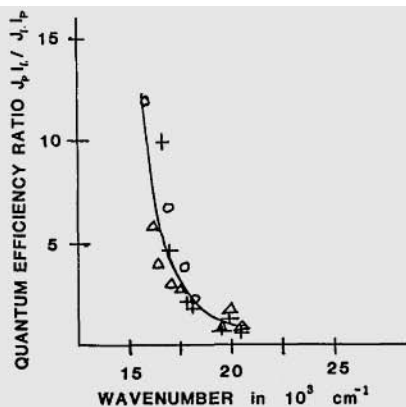


Fig. 4. Quantum efficiency ratio for the surface plasmon. J_p (mA/cm²) is the diode current density generated by the surface plasma resonance. J_i (mA/cm²) is the diode current density generated by normal incident light. I_p (μ W/cm²) is the incident intensity for the surface plasma resonance, and I_i (μ W/cm²) is the normal incident intensity. Δ is the arbitrary spacer thickness, + is the spacer thickness set by maximizing the diode output at 600 nm, and $\circ$ is the spacer thickness set by maximizing the diode output at 565 nm. The solid line is a guide for the eye.

This experiment has shown that the quantum efficiency of a Schottky photodiode can be improved by using a prism coupler to excite the surface plasma resonance in the metal contact. Furthermore, the spectral region in which an improved output was observed covered most of the visible range, and the quantum efficiency of the diode did not appear to be critically affected once a plasma resonance was excited. This makes it possible to develop either an improved concentrator-type solar cell or detector for visible radiation.

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The work described in this Letter has been submitted by John Derov in partial fulfillment of the requirement for the Ph.D. degree at the University of Lowell; he is now with the Rome Air Development Center.

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Parallel N^4 weighted optical interconnections

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While full optical interconnects of an $N \times N$ input signal array to an $N \times N$ output signal array through N^4 weighted interconnects is an important goal for optical artificial neural systems (ANSs), methods for doing this are rare. Goodman *et al.*¹ fully connected an $N \times 1$ array to a $1 \times N$ array. Sawchuk² has suggested a fixed N^4 interconnection method using replicated holograms for optical cellular logic. This works in principle but has extreme space-bandwidth requirements for large N . Sawchuk has described a 3-D dynamic interconnection network for interconnecting 2-D $N \times N$ arrays in parallel computing, but this network does not have arbitrarily variable weights.³ I hope to show a simple optical N^4 interconnection method which uses only one non-critical lens, an $N \times N$ reflective spatial light modulator and a beam splitter as components.

It is convenient to think of the $N \times N$ input array as a matrix A with components a_{kl} . Likewise the output is an $N \times N$ array B with components b_{ij} . These are interconnected by a 4-D tensor T , i.e.,

$$B = TA. \quad (1)$$

Equivalently,

$$b_{ij} = \sum_k \sum_l T_{ijkl} a_{kl}. \quad (2)$$

Let us denote by T_{ij} the $N \times N$ array of T_{ijkl} elements arranged in the same way as the a_{kl} elements. That is, the tensor T can be thought of as N^2 different $N \times N$ weight arrays of the form T_{ij} , where T_{ij} is an $N \times N$ array of T elements needed for Eq. (2). Dropping the subscript kl from T_{ijkl} to T_{ij} is done for clarity in the following.

Figure 1 shows the basic scheme. The A matrix is inserted at the right side into the optical system via a reflective spatial light modulator (SLM). An $N \times N$ hologram array (which may be so large that it needs to be demagnified by relay optics before use as shown in Fig. 1) is illuminated by a reconstruction beam and provides the $N^2 T_{ij}$ arrays. In Fig. 1, we see that the T_{ij} arriving at the reflective SLM are N^2 products of the form $T_{ijkl} a_{kl}$. These are collected in the B plane (the image of the hologram array).

In practice it may be necessary to make minor modifications on the apparatus of Fig. 1. The hologram array, SLM,

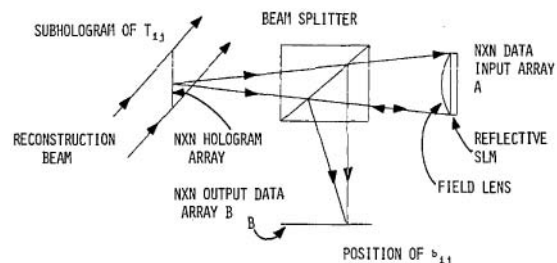


Figure 1. Configuration of a parallel optical interconnection between an $N \times N$ input array and A and an $N \times N$ output B . An $N \times N$ array of holograms each containing an $N \times N$ mask array is illuminated in parallel to produce the N^4 interconnection.

and detector array may be of different sizes. This requires relay lenses to magnify or demagnify one or more of these to achieve the Fig. 1 configuration or some simple variant of it. For example, the hologram array may be quite large. Assuming a 2-mm diam hologram to store a $1000 \times 1000 T_{ij}$ mask, we need a 2×2 -m hologram array to store 10^{12} weights. This certainly precludes some uses. A $500 \times 500 T_{ij}$ mask needs a 1-mm hologram, and we only need a 50×50 -cm array to store $(500)^4 = 67.25 \times 10^{10}$ weights. Fresnel diffraction considerations make it desirable to keep the holograms larger than or equal to ~ 1 mm. Thus if we drop to a $128 \times 128 T_{ij}$, we need a 12.8×12.8 -cm array to store the $(128)^4 = (2^7)^4 = 2^{28} \approx 2.5 \times 10^8$ weights.

To record each subhologram we must reverse Fig. 1. A point source at the i, j position in the B plane illuminates the SLM. The T_{ij} pattern is written onto the SLM. A coherent reference beam conjugate to the Fig. 1 reconstructing beam allows the subhologram to be recorded.

Optical parallel N^4 interconnections are seen to be quite straightforward. No technology breakthroughs are required to achieve $N = 10^3$ or $N^4 = 10^{12}$. Recording the master hologram as a whole or in parts may prove slow, but mass-produced copies can be made quickly and inexpensively.

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Spectral hole burning and hologram storage

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The absorption bands of organic molecules in polymer films are inhomogeneously broadened and typically cover a range of several terahertz ($1 \text{ THz} = 33 \text{ cm}^{-1}$). At very low temperatures the homogenous linewidth of the $0-0$ band of the $S_1 \leftarrow S_0$ transition often approaches the fluorescent lifetime-limited value of the order of 10 MHz. A photochemical or photophysical transformation is induced by irradiating an inhomogeneously broadened band with light from a single-mode dye laser. Only the subset of the molecules which absorb at this particular wavelength reacts. The products of this phototransformation generally absorb in a different spectral range. The dip, thus generated in the inhomogeneously broadened band, is called a spectral hole and has a width of the order of twice the homogeneous linewidth.^{1,2} Theories explaining the temperature dependence of the homogenous linewidth have been recently reviewed.³

The dip in the absorption spectrum can be associated with a stored bit. Repeating the hole burning process at different

spectral positions presents the possibility of high-capacity information storage.⁴ It has been demonstrated that data storage using the electric field as an additional dimension is possible.^{5,6} Data bits have been recorded at selected positions of laser frequency and of electrical field strength.⁵ Data readout was performed by sweeping the electric field at fixed values of the laser frequency. This is much simpler than scanning a tunable dye laser.

The shapes of the spectral holes have been determined until recently by observing either the transmittance or the fluorescence excitation scans. The application of the holographic technique for writing and reading spectrally narrow holes has been explored by Renn *et al.*⁷ It has been shown that holography is a sensitive zero-background technique which can be advantageously employed in high-resolution spectroscopic studies of organic molecules in condensed phase.⁸ In all these applications reported the hologram consisted of a simple sinusoidal grating which was produced by the interference pattern of two plane waves. A time and space-domain holographic method which provides the storage and reproduction of the time dependence of optical signals with a duration of 10^{-8} – 10^{-13} s utilizing inhomogeneously broadened media has been reported by Saari *et al.*⁹

In this letter, we show that the concepts and methods discussed above can be generalized and combined resulting in multiple storage of complex holograms in the same sample area. Examples for laser frequency selective and electric field selective hologram storage are given. Individual holograms can be retrieved by a proper sequential adjustment of the laser frequency and the electric field. It is easy to recall the individual holograms at a rate of 25 frames/s and to

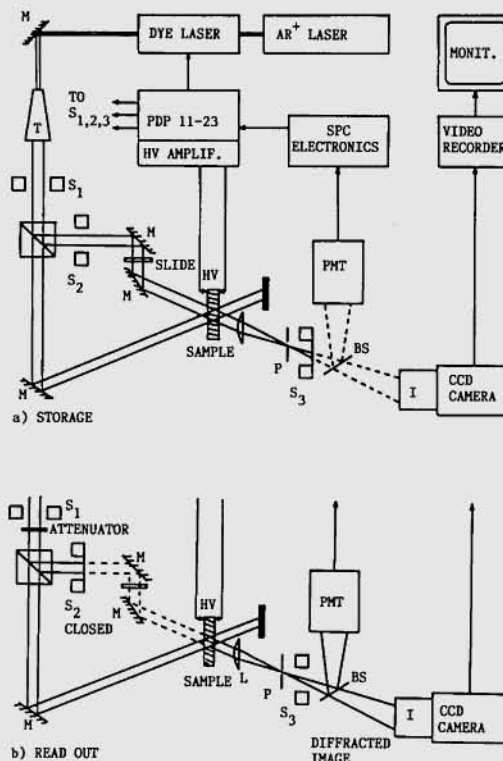


Fig. 1. Schematic view of the experimental setup used for frequency and electric field selective holographic storage and (b) reconstruction of images: BS, beam splitter; I, image intensifier; L, lens; M, mirrors; P, pinhole; S_i , electronic shutters; T, telescope.