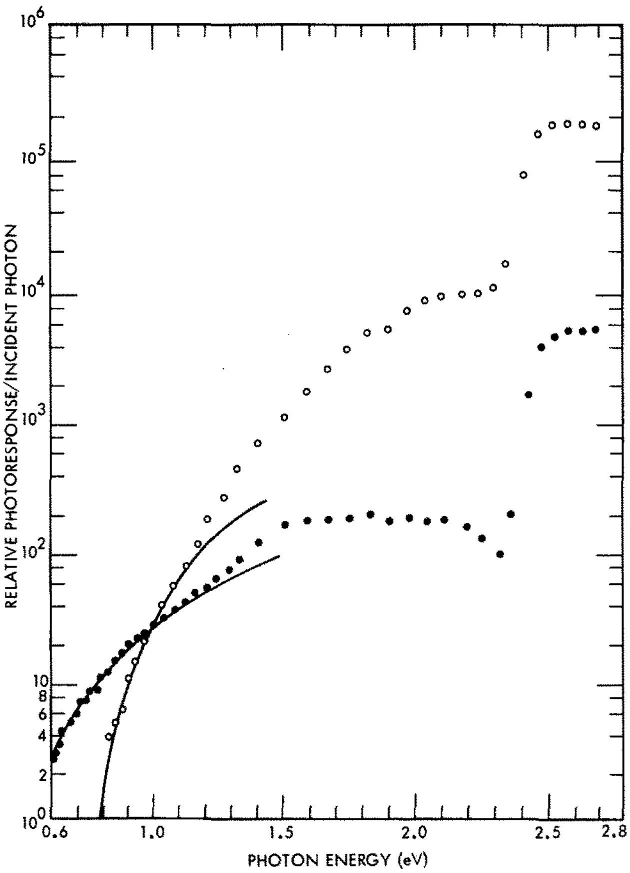

Fig. 2. Relative photoresponse per incident photon as a function of photon energy for a Cu-CdS-Cr sample before (●) and after (○) 2-min post-treatment. No significant change was noted for longer treatment times. Solid curves are the Fowler function for barrier heights: ●, 0.43 eV; ○, 0.78 eV.

from levels in the CdS with a strong level appearing at about 1.5 eV. For our films the presence of such levels was not indicated since neither photoconductivity per photon nor absorption exhibited peaks at photon energies less than 2.5 eV.

In the present study the dependence of barrier height, and hence photoemission, on metal and post-treatment is well established. However, with the possible exception of Cu, the mechanism of barrier height increase with treatment is not understood. A patchy barrier, healed by post-treatment, is not indicated since the initial data are well fitted by a single Fowler plot. The general agreement between treated-film and single-crystal results leads to the speculation that treatment brings about a redistribution of surface states to coincide closely with that for single-crystal CdS.

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HOLOGRAMS WITH NONPSEUDOSCOPIC REAL IMAGES*

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("red image" subject for second hologram; pseudoscopy = reversed relief; E)

The wavefront reconstruction process, first proposed by Gabor[1] and subsequently enhanced by Leith and Upatnieks,[2] produces three-dimensional imagery with a realism unattainable by any other known means. The hologram produces, in its two first-order diffractions, a real and virtual image (complete with all the normal parallax relations encountered in life) which are not preserved in the normal photographic process.

The virtual image is viewed by looking through the hologram as if it were a window. The real image

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is in a sense more striking, since the observer can "approach" each element of the scene as closely as he wishes. The image, however, has a serious drawback which significantly detracts from its appearance and in fact makes it difficult to observe properly; this difficulty can be roughly described by the statement that the image is pseudoscopic (i.e., shows reversed relief). There are many conflicting visual cues: near objects are obscured by more distant ones, concave surfaces appear convex, etc. Consequently, it is disturbing to view the real image.

We report here a technique for producing holograms having a real aerial image of a three-dimensional scene, in which all of the aforementioned visual anomalies are absent. This is done by construction of two holograms in succession,[3] each without the use of lenses.

First, a hologram is constructed in the usual manner (Fig. 1). This hologram is then illuminated so as to produce the reconstructed real image. This real image is then used as the subject for a second hologram (Fig. 2). In our experiment, collimated reference beams were used to maintain unity magnification throughout the process. The two holograms were recorded on Eastman Kodak type 649F spectroscopic plates.

The second hologram produces a real image in which all of the undesirable properties noted above are absent. As shown (Fig. 3), the entire reconstructed image is suspended in space between the observer and the hologram plate.

An observer experiences little difficulty in stereoscopically focusing on this image, and can perceive the original scene in its normal three-dimensional perspective. This is in contrast to the difficulty encountered when attempting to view the pseudoscopic real images of conventional holograms. Despite the two-step process involved, the final reconstructed real image is of high quality and does not exhibit a significant loss of resolution (Fig. 4).

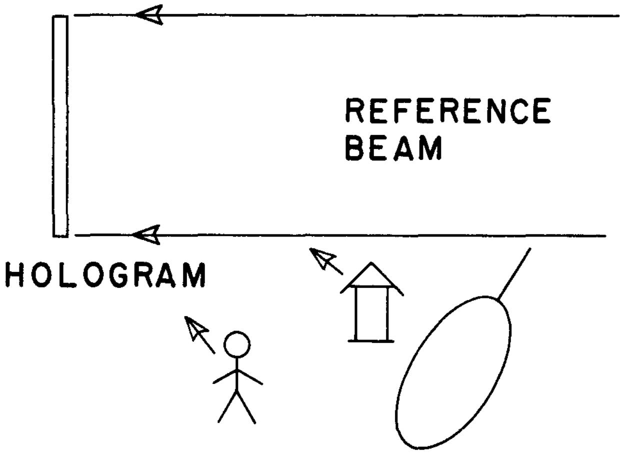

Fig. 1. Usual hologram construction arrangement.

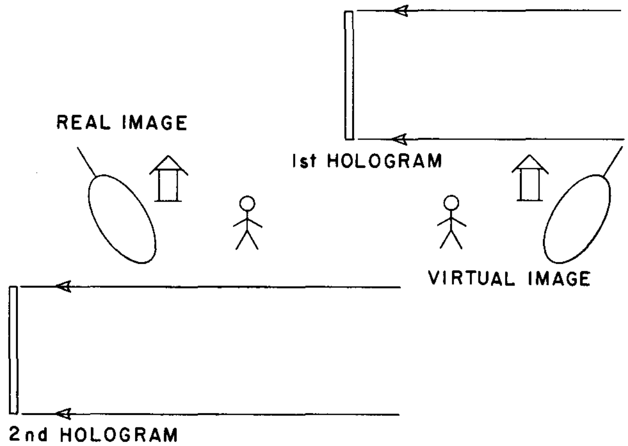

Fig. 2. Construction of hologram from the real image of another hologram.

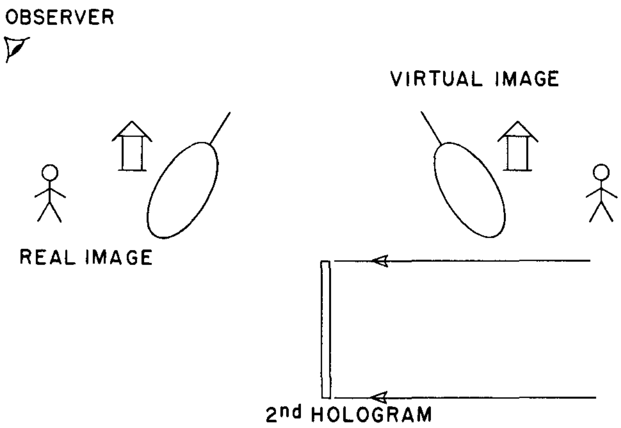

Fig. 3. Real image produced by second hologram.

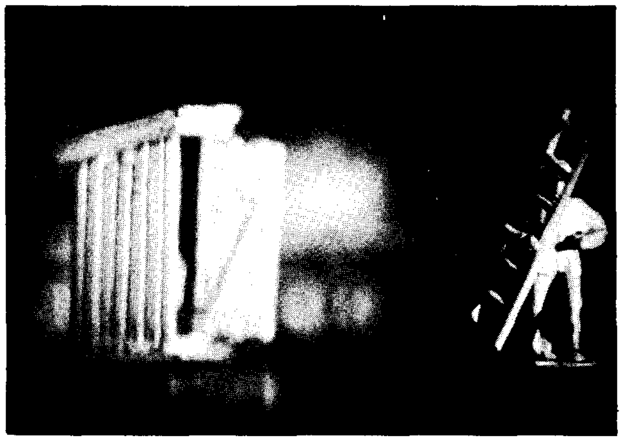

Fig. 4. Photograph of real image produced by second hologram. The photograph was made at a large F-number (4.7) to produce a small depth of field. The camera was focused on the figure of a man; any of the other objects could have been brought into equally sharp focus.

Although the above technique is a relatively straightforward extension of existing hologram techniques, it has important implications as far as possible applications are concerned. It presents a method for creating a precise and effective three-dimensional image in space in such a manner that an observer can actually "reach" the scene. The observer is no longer constrained to look through a window—the hologram plate—at the scene. This feature may be quite significant in the production of extremely realistic visual displays or simulation devices.

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EFFICIENT INJECTION ELECTROLUMINESCENCE IN ZnTe BY AVALANCHE BREAKDOWN

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(quantum efficiency 2% at 5380 Å; 77°K; Li-doped; E)

A basic problem in obtaining efficient visible injection electroluminescence in the wide-band-gap II–VI compounds is the achievement of efficient minority-carrier injection. This goal has been attained at low temperatures (e.g., 77°K) by the use of *p-n* junctions produced by diffusion techniques in $Cd_xZn_{1-x}Te$ by Morehead and Mandel[1] and in $ZnSe_xTe_{1-x}$ by Aven.[2] In the compound ZnTe, the use of alloy contacts of indium has led to low-efficiency electroluminescent diodes (less than 0.01% external quantum efficiency.[3,4] Blocking contacts to ZnTe have produced external quantum efficiencies of a few percent at 77°K, but these efficiencies were obtained only at high current densities (about 10^4 A/cm^2).[5] The efficient emission obtained by K. Weiser in avalanching *p-i-p* structures in GaAs[6] prompted us to try to make such a structure in ZnTe. A previous attempt by Fischer[7] to obtain efficient injection of minority carriers (holes) by impact ionization in an insulating region in ZnSe was relatively unsuccessful. However, under appropriate conditions such a structure (*p-i-p*, *n-i-n*, *M-i-n*, or *M-i-p*) should produce much more efficient electroluminescence than an avalanching reverse biased *p-n* junction since impact ionized holes can be swept into an *n* region (or electrons into a *p* region).

The substrate material found to be most suitable for producing avalanche structures is Li-doped ZnTe. ZnTe substrates doped with P, with Na, with Sn, with Ag, and with no intentionally added dopants were also used, but only the P-doped ZnTe led to an occasional, moderately efficient structure. The required single crystals were grown by a modified Bridgman technique from a melt containing 25 mole % excess Te and between 0.5 and 1 mole % Li. Typical bulk electrical properties of this material as grown as well as the bulk electrical properties of the *p* region after diode production are listed in Table I. The high-resistivity region required for avalanching is produced by the diffusion of an evaporated Al film (typically 0.4 mg/cm^2 on a crystal 0.5 to 1 mm thick) into the substrate at 850°C for 5 min under a Zn overpressure. This firing procedure produced an increase in the carrier concentration in the bulk low-resistivity *p*-region as shown in Table I.

Diodes were prepared from the fired substrates by lapping off one of the insulating surfaces. Contact to the bulk *p*-type region was accomplished by the use of electroless Au. Electroless Au, Ag epoxy, or In could be used to contact the high-resistance Al-diffused region with similar results for all three

Table I. Modification of Bulk Electrical Properties of Li-doped ZnTe by Diode Preparation Technique

Parameter		Value before Firing	Value after Firing
Resistivity		0.29 Ω-cm	0.11 Ω-cm
Hole concentration	300°K	2.2×10^{17} cm^{-3}	8.5×10^{17} cm^{-3}
Hall mobility		97 cm^2/V-sec	70 cm^2/V-sec
Resistivity		1.75 Ω-cm	0.97 Ω-cm
Hole concentration	77°K	5.1×10^{15} cm^{-3}	4.1×10^{16} cm^{-3}
Hall mobility		630 cm^2/V-sec	160 cm^2/V-sec