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Helium-Neon Laser: Thermal High-Resolution Recording

Abstract. *Scan-line recording by means of a moving laser spot has been achieved on metallic and organic thin films. Recording rates of the order of one million spots per second were obtained with a laser beam power of 38 milliwatts at the recording surface. Typical recorded line widths were of the order of 2 microns.*

Basic considerations indicated that laser recording of very high resolution (> 400 lines per millimeter) should be possible with what we now term heat-mode recording. We define laser heat-mode recording as any detectable physical or chemical change in the recording medium caused by a temperature rise due to absorption of energy from the laser beam. In general, such a recording is "real time" since the recorded data is immediately available for sensing and does not make use of a latent image effect requiring subsequent processing or treatment.

Our preliminary theoretical studies indicated that high-resolution, heat-mode recording should be possible on thin films with optics of reasonable numerical aperture (> 0.2) with a low divergence, uniphase laser beam with an output greater than 20 mw. Practical considerations dictated that the laser should be continuous wave. The particular wavelength of the laser was of minor concern in that we were free to select recording media that showed adequate absorption at the laser wavelength. We preferred a laser wavelength in the visible range because of the availability of suitable optics, the convenience of working in the visible portion of the spectrum, and the high resolution possible with visible radiation.

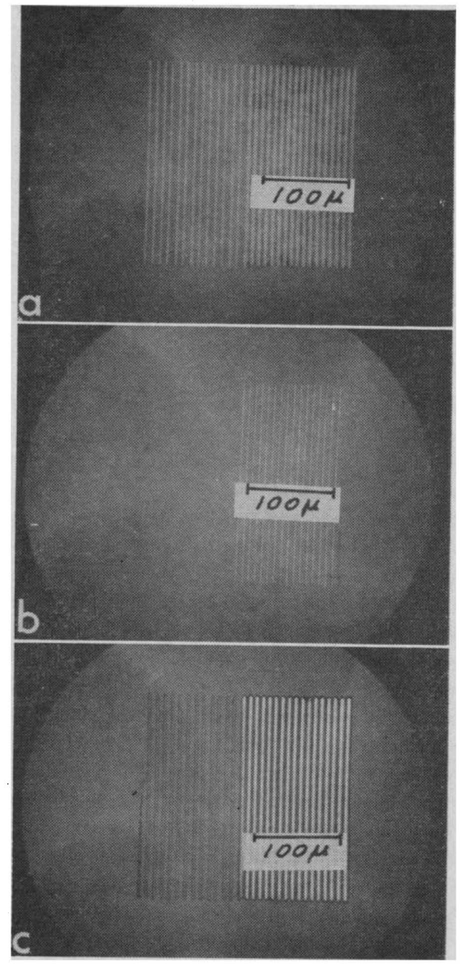

Fig. 1 (top right). High-resolution recording by laser thermal effects on thin films, illustrating (a) lead, (b) tantalum, and (c) a triphenylmethane dye in a plastic binder. Left half of a, b, and c at 0.1 msec per scan line, and right half at 1.0 msec per scan line; beam power 38 mw.

A Spectra-Physics model 125 helium-neon laser was used for our initial experiments. Its uniphase power output at 6328 Å exceeded 50 mw with a beam divergence that was within a factor of 2 of being diffraction-limited. Apparatus was constructed to move a focused spot at the recording medium through a series of parallel lines. The optical system was carefully designed to conserve power and to limit losses to unavoidable reflections. Although desirable, optical surfaces were not coated with antireflection films for the 6328-Å wavelength. The system could also operate without the scanning motion to record single spots.

The cross-sectional distribution of energy in the laser beam has been assumed to be gaussian. The radius of the beam is defined as the distance from the center of the beam to the point where the flux density has fallen to 0.135 of its peak value. When the laser beam is focused to a small spot, its distribution remains gaussian. The final recording lens had a 0.4 numerical aperture and produced a focused spot, as defined, which was 1.8 μ in diameter. The maximum power of the beam transmitted to the recording medium was 38 mw. This corresponds to an average power density of 1.5×10^6 watts/cm^2.

The recording media have been in the form of thin films on glass sub-

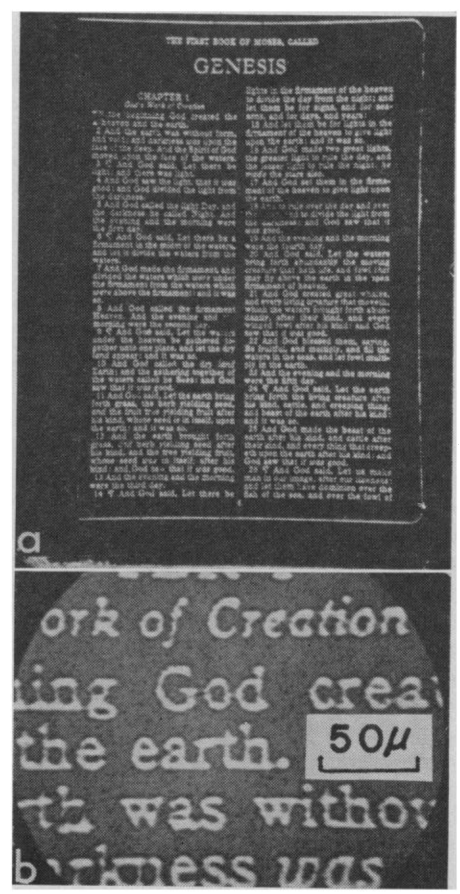

Fig. 2 (bottom right). A facsimile-type laser thermal recording of the first page of the Bible, showing (a) the complete page, and (b) a portion of the page to illustrate detail.

Table 1. Line widths and spot recording rates.

Fig.	0.1-Msec scan		1.0-Msec scan	
	Line width (μ)	Spots/sec	Line width (μ)	Spots/sec
1a	1.8	1.3×10^6	2.0	1.2×10^5
1b			2.0	1.2×10^5
1c	2.5	9.6×10^5	4.5	5.3×10^4

strates. Evaporated films were generally in the 500- to 1000-Å range, and the organic coatings 4 μ or less. Of the large number of media investigated, the discussion here will be limited to the following: a 500-Å evaporated coating of lead; a 500-Å evaporated coating of tantalum; a 1.0-μ coating of a triphenylmethane dye in a plastic binder.

In-focus line patterns were recorded on the three media with beam power, horizontal velocity, and vertical velocity being the independent variables. The recorded patterns are 240 by 240 μ. A beam power of 38 mw at the recording medium was used in each case. The left half of each pattern was recorded at 0.1 msec per vertical scan line, and the right half at 1.0 msec per vertical scan line. In the case of tantalum (Fig. 1b), beam power was insufficient to record the left half of the pattern. Measurements of the width of the clear portion of the scan lines for Fig. 1, a, b, and c, were made (Table 1). Knowledge of this line scan time permits calculation of the effective spot recording rate. The minimum line scan time was limited by the apparatus to 0.1 msec.

While the measurements on the dye-plastic sample (Fig. 1c) were made with respect to clear lines, this coating also exhibits a darkening effect on the edges of the cleared tracks. At higher scan rates, or lower beam powers, or both, this can lead to an overall image which is darker than the background, and need not be accompanied by a clear track at the line center. A similar effect, but resulting from different mechanisms, occurs with a number of evaporated films.

We recorded a page of the Bible by direct document input (by means of a facsimile-type optical scanner), and an ultrasonic diffraction-grating light shutter for beam modulation. The recording objective in this case had a numerical aperture of 0.2 with a useful flat-field diameter of 3 mm. The 3-mm field contained 1600 scan lines of which 1200 were actually used in recording the document. It should be noted that the resolution of the recording was limited by the optical resolution of the document scanner rather than by the laser recorder.

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Sedimentary Environments in a Marine Marsh

Abstract. *Several foraminiferal assemblages are recognized in* Spartina-Salicornia *marshes along the Pacific and Gulf of Mexico coasts. Continuous recordings in one Pacific marsh show considerable diurnal and seasonal variation in* pH, *oxygen, water temperature, and salinity. This is related to tidal flushing, air temperature variations, sunlight duration, and marsh plant metabolism.*

Modern marine sediments have been studied extensively to discover relationships between types of sediment and the marine environments in which they accumulate (*1, 2*). Organic sedimentary particles generally are better environmental indices than detrital mineral grains because they are produced where they are found (*3, 4*). Patterns of sediments in the modern oceans, including the organic particles, have been used to decipher probable environments in older oceans represented by the record in ancient marine sediments (*5, 6*).

Considerable information is available on distributions of sedimentary materials in the modern ocean. Information about the marine sedimentary environments, however, generally is inadequate and is confined to a few temperature and salinity measurements, depth of water, and topographic location. Such data are of limited value in defining a marine environment and have little reality from the point of view of the living organisms which contribute skeletal material to the sediments. Extremes, durations, and means of all important environmental parameters are essential for a realistic analysis.

Marine marshes, which are widespread, are an important part of marginal marine sediments, and are extensively preserved in ancient marine rocks. Marsh sediments have been little studied, with some exceptions (*7*). We have examined some aspects of the field distributions of marsh sediments, and have attempted to partially define the environments in which they are accumulating in one marsh. The sedimentary particles studied are the foraminifera; they are abundant, they are important contributors of sedimentary particles, and they are produced where they are found.

Distributions of foraminifera are summarized for numerous marshes along the Texas coast in the northwestern Gulf of Mexico and for the Pacific coast of North America (Fig. 1). The vegetation of these marshes is generally composed of an assemblage dominated by *Spartina* at the lower elevations, just above the unvegetated tide flats, and an assemblage dominated by *Salicornia* at a higher elevation (*8*). Actual elevations of these plant communities are related to the tide range. Inorganic components of the sediment range from silty sand to silty clay, depending on the marsh and the location within the marsh.

At least three marsh zones can be identified by foraminiferal assemblages (Fig. 1). This zonation occurs in hypersaline marshes and in those having salinities less than normal sea water, and frequently is developed over a very short distance. We have attempted to define a marsh environment by measurements of as many environmental factors as possible in one marsh. Continuous and simultaneous recordings have been made of values of salinity, water temperature, air temperature, sodium ion, chloride ion, oxygen, pH, Eh, sulfide ion, light intensity, wind velocity, and tide level. These measurements have been made for approximately 1 year to obtain estimates of extremes, means, and durations of different values of the various parameters. The instruments used are mostly readily available, but many have required modification and special assembling for use under field conditions (*9*).

Recordings were made in a small *Spartina-Salicornia* marsh at Mission Bay, California, sufficiently near the laboratory so that the equipment could be serviced frequently. The sensors were