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HOLOGRAPHIC STORAGE OF ACOUSTIC SURFACE WAVES WITH SCHOTTKY DIO--ETC(U)
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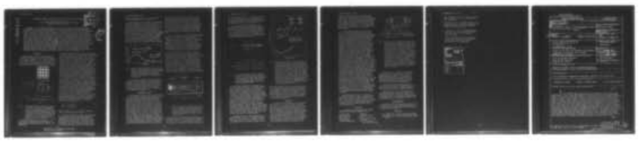

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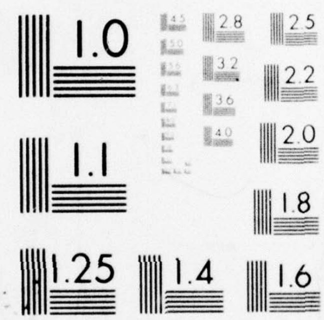

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HOLOGRAPHIC STORAGE OF ACOUSTIC SURFACE WAVES WITH SCHOTTKY DIODE ARRAYS*

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ABSTRACT Silicon Schottky-diodes have been used to store images of surface acoustic waves propagating on lithium niobate. These images were subsequently employed to provide programmable matched filter or coherent integration functions. This technique could also be used to holographically store a large number of acoustic beams to provide a storage capacity as large as 10^5 bits of information. The basic storage element is a Schottky diode with an overlay of polysilicon. Many such diodes are arrayed on centers which are less than an acoustic wavelength apart. When the acoustic signal is in position beneath the diode array, the diodes are forward-biased for several nsec, which causes charge to flow to the diode contact in response to the piezoelectric field of the surface wave. These charges diffuse into the polysilicon in several μs, after which a succeeding signal can be overlayed in the array. These charges, which are an image of the acoustic signal are retained in the polysilicon for as long as 100 ms. The stored image is proportional to the acoustic signal in every respect, including the amplitude, phase and wavefront details. This procedure could be repeated for many acoustic beams, and a subsequent signal along a given stored beam causes an electrical signal to appear across the silicon-lithium niobate composite which is proportional to the cross-correlation of the signal with all stored images. This gives rise to the desired output signal, plus undesirable cross-talk signals. Also the desired signal is relatively weak, and its signal-to-noise ratio needs to be increased with a coded interrogating signal and a matched filter.

Introduction

Acoustoelectric signals have been stored and coherently overlayed in an array of Schottky diodes with polysilicon contacts[1]. The principle of operation of the device is shown in Fig. 1. A strip of silicon is positioned a fraction of a micron away from the surface acoustic wave delay line. The silicon interface is covered with a 2-dimensional array of Schottky

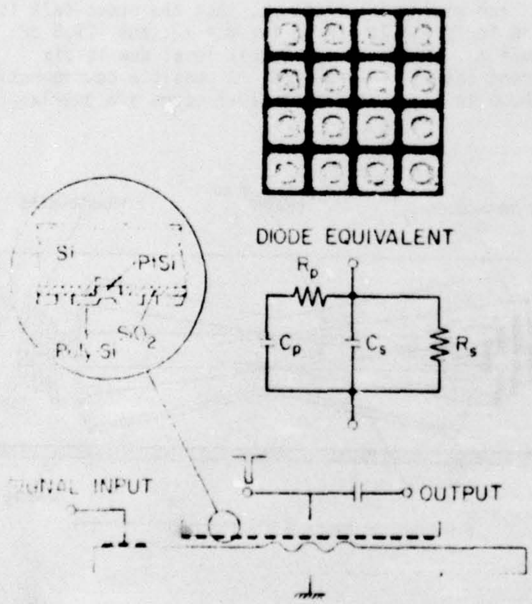

Fig. 1 Schottky diode memory-correlator structure with polysilicon overlay. The equivalent circuit of a single diode has a diode resistance and capacitance R_s and C_s, and polysilicon resistance and capacitance R_p and C_p. Dimensions are chosen to provide diode time-constants of 10^{-9} and 10^{-1} sec with forward and reverse bias, and polysilicon time-constant of 10^{-6} sec. The picture is of a diode array on 12.5 μm centers.

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diodes with polysilicon contacts, located on centers less than 1/2 acoustic wavelength apart. An equivalent circuit of an individual Schottky diode is shown in the figure. When the diode is biased in the forward direction $R_S^+C_S^+ \sim 10^{-9}$ sec and in the reverse direction $R_S^-C_S^- \sim 10^{-1}$ sec. The carrier diffusion time constant in the polysilicon is $R_pC_p \sim 10^{-6}$ sec. An intense acoustic signal on the surface of lithium niobate has a piezoelectric potential of several hundred mV. When the signal is in position beneath the diode array, the diodes are biased in the forward direction for several nsec, during which time charging currents can flow from the bulk silicon into the platinum silicide contacts (C_S^+). The distribution of charge among the diode capacitors in the array has a component which is an image of the piezoelectric potential, as well as a uniform component due to the bias potential. The uniform charge back-biases the diodes, which provides a time constant of the order of 0.1 sec. The charge on the platinum silicide contacts C_S^- diffuses into polysilicon capacitor C_p in a few μs. For a subsequent signal, the diodes are forward-biased again for a few ns, which is not a long enough time interval to discharge C_p. As before, the charge in the platinum silicide diffuses into the polysilicon, which accumulates a succession of charges. This process is repeated until the potential in C_p approaches the peak potential on C_s. The net transfer of charge from the diode to the polysilicon during any sampling interval is proportional to the difference of potential on C_p and C_s. As the potential on C_p increases, the incremental charge transfer decreases. For the case where the same signal is sampled periodically, the charge Q_N increases with respect to the initial charge Q_1 according to the relationship

$$\frac{Q_N}{Q_1} = \frac{1 - e^{-(N+1)\,T/\tau}}{1 - e^{-T/\tau}} \qquad (1)$$

where $\tau = R_S^-(C_S^- + C_p)$, T = time interval between successive periodic writing impulses.

If the acoustic signal is absent, then successive writing impulses provide a uniform potential among the diodes, and sufficient charge is ultimately transferred from C_S^- to C_p until the potential on C_p approaches the potential on C_S. With signal present the potential on C_S^- could change from pulse to pulse. The charge on C_p either increases or decreases with each writing, depending on the sense of the potential difference between C_S^- and C_P. Thus a true analog image of the surface waves can be stored.

The distribution of charge among the polysilicon capacitors creates a spatial variation in the carrier distribution in the bulk silicon and subsequent signals cross-correlate with this carrier distribution[2]. The strength of the cross-correlation signal is proportional to the stored charge in the polysilicon, and the results obtained with overlayed identical pulses are shown in Fig. 2. Notice that the accumulated charge does indeed follow the logorithmic law expressed in Eq. 1 if the time constants are used as indicated in the figure. If a large number of linear signals are to be stored, then the input signal strength should increase exponentially to compensate for this logorithmic effect. A linearity margin of 5 dB is advisable if data is to be recorded with good fidelity.

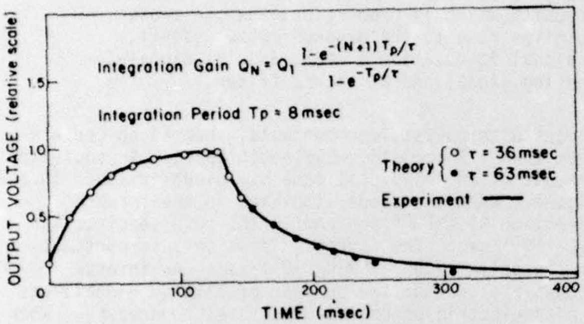

Fig. 2 Output voltage versus time, for 15 successive overlaps. The data was obtained by writing an identical signal every eight ms, and by reading the stored pattern continuously between writings. There appear to be two storage time-constants of 36 and 63 ms associated with the diode array.

Acoustoelectric convolvers have been reported elsewhere in this Proceedings[3] which have a bandwidth of 100 MHz, a carrier frequency of 300 MHz and an interaction length of 10 μs. The device is capable of providing an output signal level of -22 dBm with input signal levels of +18 dBm. This identical technology could be employed towards the realization of a holographic storage device.

Holographic Storage

The charge distribution of any one signal image in the diode array is a precise replica of the acoustic wave, and every detail of the wave, including the amplitude, phase and spatial configuration of the wavefronts is recorded. This is the end result of conventional holography, and the use of the work here implies only the retention of wavefront information but not necessarily the usual process. A holographic acoustic memory would be competing with other serial memories including magnetic disk, bubble domain, and CCD storage memories. The potentially unique feature of the acoustic memory is that it is essentially an analog storage device, and that it could store data at a rate which is an order of magnitude greater than what is available with all other types of serial memories. Another attractive feature of holographic storage is that each bit of information is distributed among thousands of diodes, and the storage capability is virtually unaffected by a random distribution of defective diodes throughout the array. By contrast, chains of CCD and bubble domain devices require the sequential transfer of data from one link to the next, and a single defective link may make a whole chain of storage elements inoperative. If several tens of beams are to be overlayed in the same diode array, then great care must be taken to minimize cross-talk. The data must be stored in a manner which places one data stream in an orthogonal relationship to all others. This orthogonality could be obtained by tilting one acoustic beam with respect to others, by encoding the data with orthogonal codes, and by exciting orthogonal propagating modes along any one beam.

The use of temporal codes for separating overlayed data leads to a reduction in the data bandwidth. For example, if each sample of information is to be encoded with 10 bits of code then data can be entered at a rate of only 1/10th the bandwidth if code orthogonality is to be preserved. If the code has a bandwidth of 100 MHz then data can be entered at a rate no greater than 10 MHz. Since CCD devices operate at this rate, it would not be interesting to develop a new memory which has similar limitations, and this form of storage enhancement is therefore rejected.

Tilting the beam could provide, in principle, perfect beam orthogonality at a given frequency. This condition can only be approximated with a finite bandwidth. The cross-talk level between an interrogating signal and a stored image is proportional to $(\sin\theta)^2/\theta^2$ where $\theta = \pi(/\lambda)\sin\phi$ radians, L = beam width, λ = wavelength, ϕ = angle between wavefronts of stored image and signal. It can be shown for a fractional bandwidth of 33%, and for the case where the read-out signal does not correlate with storage data, and where $\sin\phi = 6m\lambda_0/L$, that the cross-talk is -25 dB for $m = \pm 1$, -28 dB for $m = \pm 2$, and -29.5 dB for $m = \pm 3$. Thus the cross-talk level due to six adjacent beams is -19 dB RMS. A possible configuration is shown in Fig. 3 in which seven beams are overlapping

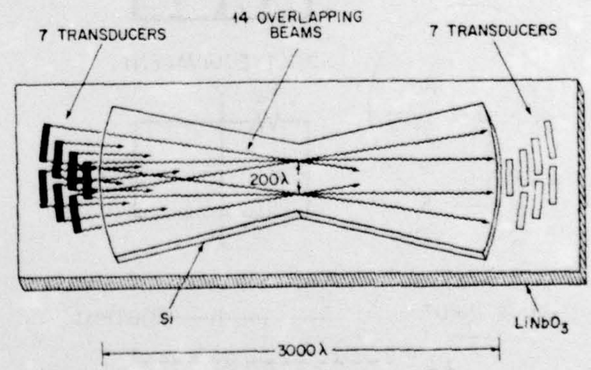

Fig. 3 Schematic view of 14 overlayed acoustic beams on $LiNbO_3$ beneath a silicon Schottky-diode array. The 200 λ-wide beams are separated by an angle of 6/200 radians. There are seven beams on each side of the structure. Each transducer set consists of seven 2.5-finger-pair transducers.

in the same region, propagating from left to right. An additional seven beams could be added which propagate from right to left. Any one beam fills a fraction of the diode array. Thus a certain amount of signal is lost because of the capacitive loading associated with the non-participating diodes. For the situation where each of the seven beams has a time-bandwidth product of 1000 and a fractional bandwidth of 33%, only 60% of the available diodes are filled by any one beam, which corresponds to a parasitic loss of -5 dB.

A third way to achieve orthogonality is to employ orthogonal modes along any one beam direction. For example, transducers could be used to introduce phase reversals across the beam aperture as shown in Fig. 4. The phase reversal is created by reversing the transducer finger connections[4] to assure good isolation between modes over a wide bandwidth. Seven wave-front patterns are shown in the figure which are orthogonal with respect to each other.

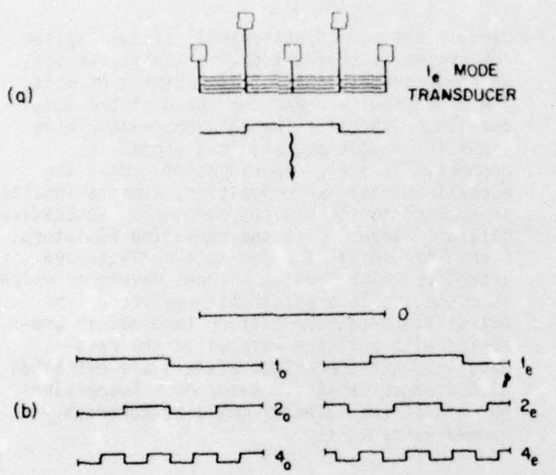

Fig. 4 a) Typical transducer showing π phase discontinuities consistent with the 1_e mode. notice that the transducer finger connections are reversed at the π phase discontinuities. b) seven orthogonal modes. The cross-correlation amplitude between one mode and any of the others is zero.

A preliminary experiment was performed with a narrow-band memory correlator, to test this hypothesis. The results are shown in Fig. 5. For example, a signal is entered with transducer 1 and stored. A reading impulse is entered in each of the four transducers, and the peak amplitude of the output signal is measured. An output signal of -40 dBm is obtained at 90 MHz, when the read impulse is entered at terminal 1. If a read impulse is entered at terminals 3 or 4, on the other side of the device, then the output signal is approximately at the -75 dBm level, which corresponds to an isolation of -35 dB. In this instance, the transducers were jogged instead of reverse-connected, which results in good isolation only at one frequency. However, when the read impulse was entered in beam terminal 2, cross-talk was observed because of electrical coupling between terminal 1 and 2. This caused each transducer to radiate the initial signal, which was stored. The cross-talk, which is a result of this electrical coupling, could be reduced to the -35 dB level with suitable grounds.

In certain situations, when digital data is bi-phase encoded on a carrier, it is possible to store two sets of signals which are orthogonal in phase with respect to a local oscillator signal. Thus two sets of data could in principle be entered along a

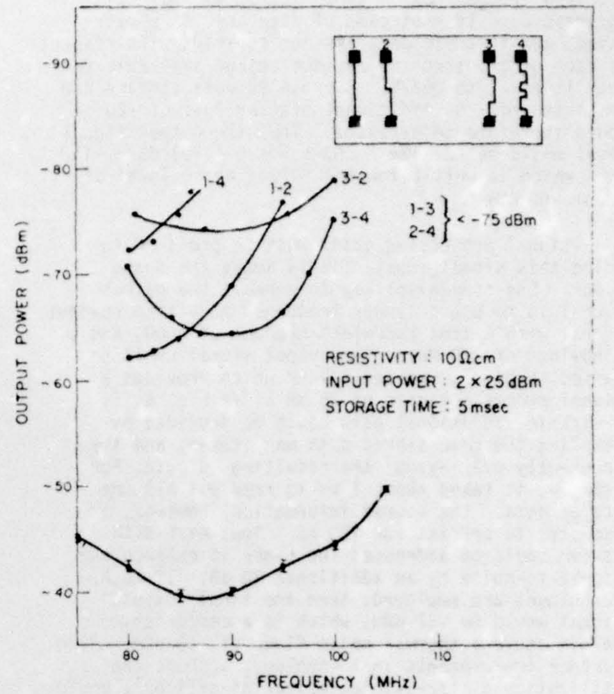

Fig. 5 Experimental demonstration of orthogonal modes. The data were obtained by storing CW pulses in a Schottky diode array, and then observing the cross-correlation signal 5 msec later with a CW read pulse. Four dog-leg type transducers were applied to the substrate as shown. If the read-signal is applied to the same terminal as the write-signal, then the reference output signal is at a level of -40 dBm. If the read signals are applied to a transducer which is on a side opposite to the write-transducer, then the cross-correlation signal is -35 dB below the reference level. The electrostatic coupling between transducers 1-2 and 3-4 is approximately -20 dB. This causes the storage of a parasitic signal which is subsequently read out.

particular beam with a particular mode configuration. If all these options were to be exploited, we could have a potential capacity of 14 beams X 7 modes/beam X 2 phases/mode = 196 data streams, each with a storage capacity of 1000 bits of information. These 196,000 samples of data could be stored in an area of $10^6\lambda^2$. At 300 MHz $\lambda = 10\mu$, which implies an area of 1.0 cm^2, which is equivalent to more than 10^6 bits of stored analog data per in^2.

Limitations

In practice many difficulties arise in connection with overlaying this amount of data in a Schottky diode array. For example, the output signal is far below the output noise level, and special techniques have to be employed to remedy this situation. The maximum output signal level is -22 dBm with currently available technology, provided the stored data stream fills all diodes, and the read-out signal overlaps the stored signal at every point. This is not the case in the memory where the interrogating impulse addresses only one bit of data at a time. The output signal amplitude is reduced by the time-bandwidth product of the stored data, which causes a -50 dB loss. An additional -5 dB of linearity margin is required if the data is to be stored without gain compression. If N streams of data are to be overlayed, and if these data are not coherent with respect ot each other, then the maximum charge available per beam is equal to $Q_N/\sqrt{N}$. Suppose 98 data streams are to be stored. An additional overlay loss of -20 dB would therefore be expected. Thus the output signal level would be -22 dBm - (60 + 5 + 5 + 20) dB = -112 dBm, which is well below the output noise level of about -90 dBm.

Signal processing gains must be provided to bring this signal substantially above the noise floor. One convenient way to enhance the output signal is to use a linear frequency-modulated readout signal with a time-bandwidth product of 5000, and a bandwidth of 100 MHz. The output signal would be passed through a matched filter which provides a signal processing gain of 35 dB as in Fig. 6. If desirable, additional gain could be provided by sampling the same stored data many times, and then coherently overlaying[1] the resulting outputs. For example, it takes about 1 ms to read out all the stored data. The stored information, however, is expected to persist for 100 ms. Thus each data stream could be addressed 100 times to enhance the signal-to-noise by an additional 20 dB. If both techniques are employed, then the final output signal would be -57 dBm, which is a comfortable margin above a thermal noise floor of -90 dBm. Also further improvements in technology, such as the utilization of 1/2-μ-thick epitaxial silicon[5], could provide an additional 10 dB of sensitivity. A reasonable minimum output signal-to-noise ratio is 12 dB. Thus in principle, this memory could provide a dynamic range of 20 dB in the short term, and as much as 30 dB in the future, for 10^5 analog entries. However, it is unlikely that this dynamic range is available, unless new, and as yet unavailable methods are discovered to reduce cross-talk among stored data streams. For example, according to some preliminary analysis, the isolation between a beam 200λ wide, and six nearest neighboring beams which are separated in angle by 0.03 radians, is approximately -19 dB RMS. The cross-talk between two orthogonal modes, or between two signals with orthogonal phase, is expected to be no better than -35 dB below the output signal. Storing seven data streams in seven orthogonal modes yields a cross-talk at a level of -27 dB RMS. Thus the net cross-talk due to the modes along any one particular beam plus the cross-talk between beams is expected to be at a level of -18 dB RMS below the maximum signal. Clearly, this limits the dynamic range to several dB, and the device shown in Fig. 6 is suitable only for the storage of digital phase-encoded data.

Since the cross-talk level is expected to be at -18 dB on the average, there is little point in improving the signal-to-noise ratio beyond -20 dB, which is equivalent to an output signal level of -70 dBm. With current technology, it should be possible to achieve this with a frequency-coded read pulse having 35 dB of signal processing gain, plus 5 successive read cycles.

Conclusions

We have described a potential digital buffer memory with the following characteristics:

Input data rate:	10^8 bits/sec
Output data rate:	10^8 bits/sec or less
Access time:	210 μs
Storage capacity:	10^5 bits of binary data
Storage density:	10^6 bits/in
Intrinsic Storage time:	0.1 sec, or unlimited with refresh provision.

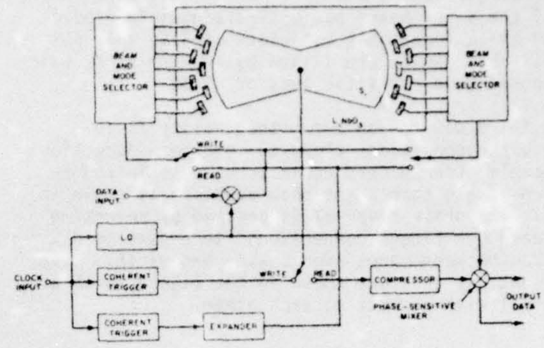

Fig. 6 Circuit diagram of holographic storage system. The system is controlled with a master-clock, which accurately controls the timing of write and read impulses, and the phase of the local oscillator signal. The data phase-modulates a carrier frequency, and this signal is connected to one of 98 radiators. When the acoustic signal is in position, a write-impulse is applied to the silicon terminal. Successive data are connected to the remaining radiators. A read-trigger is applied to a surface-wave expander, which creates a coded waveform, which is connected to a particular radiator. The output signal at the silicon terminal is processed with a filter matched to the read-waveform, and the output signals are extracted with a phase-sensitive detector. Successive outputs of the detector could be coherently summed as necessary.

Since each bit of stored data is distributed among 3500 diodes, it is possible to use silicon diode arrays with a relatively large number of randomly-distributed defects. Thus the yield in manufacturing these devices could ultimately be relatively high, despite many defects per device. This might lower the cost of manufacturing this memory relative to other kinds of memories.

Diode arrays have already been developed for silicon targets of vidicons. The additional cost to develop this kind of memory is likely to be modest with respect to other kinds of exotic memories.

Further advances in the art of reducing cross-talk among stored data streams could lead to an analog storage device with a dynamic range of 30 dB. The equivalent digital storage capacity would thereby be increased to 14 x 10^5 bits, which corresponds to a storage density of 14 x 10^6 bits/in^2.

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References

1. K.A. Ingebrigtsen, E. Stern, "Coherent integration and correlation in a modified acoustoelectric memory correlator", A.P.L., vol. 27, No. 4, 15 Aug., 1975, pp. 170-172.

2. K.A. Ingebrigtsen, et al, "A Schottky diode acoustic memory and correlator", A.P.L., vol. 26, 15 July 1975, pp. 596-598.

3. J. Cafarella, et al, "Programmable matched filtering with acoustoelectric convolvers in spread spectrum systems", Proceedings of the 1975 Ultrasonics Symposium, IEEE: New York, 1975.

4. R. LaRosa and C.F. Vasile, "Broadband bulkwave cancellation in acoustic surface wave devices" Elec. Lettrs., vol. 8, No. 19, Sept. 21, 1975, pp. 478-429.

5. A. Bers, "Non-linear interactions of acoustic surface waves with electrons at semiconductor surfaces", 1972 Ultrasonics Symposium IEEE: New York, 1972. (unpublished)

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