# Edge detection readout signal and cross talk in phase-change optical data storage

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# Edge detection readout signal and cross talk in phase-change optical data storage

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Readout signal, noise, and cross-track cross talk were investigated for edge detection in a phase-change optical data storage system. Both theoretical and experimental results indicate that edge detection has a performance superior to the conventional detection of reflectance variations, especially when the amorphous marks are shorter than the size of the focused spot. More than 50 dB of carrier to noise ratio for marks of 0.36 $\mu$m in length is obtained using light at a wavelength of 690 nm and an objective lens of 0.6 numerical aperture. Diffraction analysis on the cross talk has shown that, in the scheme of land-groove recording, there is no optimum groove depth which can cancel the cross talk from adjacent tracks. 
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As the demand for data storage capacity continuously grows, data storage technologies are being driven to higher areal densities. High density in optical data storage can be achieved in many ways.[1–3] Conventionally, a readout signal is obtained by differential detection in magneto-optical (MO) storage or by direct integration of the reflected light in phase-change (PC) optical storage [hereafter referred to as sum detection (SD)]. Mark edges are usually determined by slicing the level of the detected signal at some standard levels but this method suffers from intersymbol interference when reading densely spaced marks. Edge detection (ED), is a direct optical detection for mark edges. The readout signal is the difference between two halves of a split detector.

Theoretically, ED has advantages over conventional level detection, such as high contrast[4] and the ability to identify edges of densely spaced marks.[5] In MO storage,[6] edge shift of short marks using ED was found to be lower than that using differential level detection[7] but in other aspects, such as signal and noise levels, ED was inferior to differential level detection.[7,8] In PC storage,[9] ED noise levels were confirmed to be lower than SD noise levels. In this work we present results on ED readout signal, carrier-to-noise ratio (CNR), and cross-track cross talk characteristics in the scheme of land-groove, as well as comparison with SD for PC optical data storage.

A simple readout system for edge detection on PC media is depicted in Fig. 1. A linearly polarized and collimated laser beam propagates through a polarizing beam splitter (PBS), a quarter-wave plate (QWP), and is then brought to focus by an objective lens on a PC medium. The reflected light from the medium is detected by a split detector. The differential output between the two halves (D1, D2) of the detector generates the ED signal. In the absence of any mark, the two halves of the detector produce identical currents and the net signal is zero. When the medium moves along X direction, the leading edge of a mark diffracts the reflected light preferertially toward one half of the detector, creating a signal pulse; whereas the trailing edge of the mark diffracts the light toward the other half of the detector to create a signal pulse of opposite polarity. The peaks of these pulses identify the edges of the marks.

From the theory of scanning microscopy, a signal current, $i_{\text{sig}}$, at the output of the readout channel can be written as

$$i_{\text{sig}}(u,v)=\int\int\int dm\,dn\,dm'\,dn' \times C(m,n,m',n')r(m,n)r^*(m',n') \times \exp\{-2\pi i[(m-m')u+(n-n')v]\}. \quad (1)$$

Here $m(m')$ is spatial frequency in the X direction; $n(n')$ is spatial frequency in the Y direction; $C(m,n,m',n')$ represents the optical transfer function (OTF) of the readout system;[10] $r(m,n)$ is Fourier transform of the amplitude reflectance coefficient of the medium; and $(u,v)$ are the coordinates of the focused spot in the XY plane.

Figure 2 shows the modulation transfer function in the X axis, namely $|C(m,0,0,0)|$, as a function of spatial frequency for both ED and SD. It is seen that SD and ED have the same $|C(m,0,0,0)|$ value at $m\geq 1$. At $m<1$, ED has a substantially lower $|C(m,0,0,0)|$ value. This means that, at low frequencies, $C(m,0,0,0)$ values are suppressed, and in particular, the dc bias component is totally eliminated in the scheme of ED. The absence of the dc bias component yields a high-contrast image of marks.

Figure 3 shows the peak-to-peak (p–p) amplitude of the signal and its first harmonic as a function of data frequency ($f$) for both SD and ED, obtained by using the computer program DIFFRACT.[11] In these simulations, the incident beam is assumed to be Gaussian, light wavelength $\lambda=0.69$ $\mu$m, and numerical aperture of the objective lens NA=0.6. The medium is assumed to contain periodic, 0.8 $\lambda$ wide marks of 50% duty cycle along a track assumed on the medium. For

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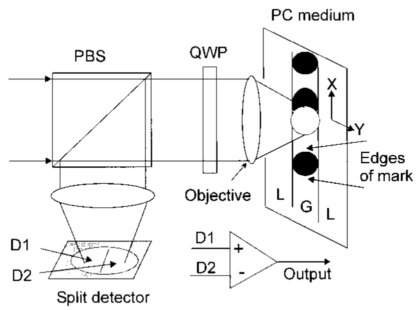


FIG. 1. A schematic diagram showing a PC readout system for edge detection. In this figure, *L* represents land track whereas *G* represents groove track.

SD, amorphous marks are assumed to have reflectivity $R_a = 0.6\%$, crystalline spaces have reflectivity $R_c = 20\%$, and the phase difference between the light reflected from marks and that reflected from crystalline spaces is $\phi_{ac} = 0$. For ED, $R_a = R_c = 20\%$ and $\phi_{\mathrm{ac}} = \pi/2$ are assumed.

From Fig. 3(a), it is observed that, at $f < \mathrm{NA}/\lambda$, ED signal amplitude remains a high level. At $f > \mathrm{NA}/\lambda$, it drops. For SD, the signal begins to drop at $f \geqslant 0.5\ \mathrm{NA}/\lambda$. Evidently, ED signals decrease more slowly with increasing frequency than SD signals do. At $f > 0.6\ \mathrm{NA}/\lambda$, ED has a higher signal level than SD has. In Fig. 3(b), with increasing frequency, the C value for SD monotonically decreases but for ED it first increases, then decreases. At high frequencies, ED has a higher C value than SD has. The behavior of the C value is understandable. For SD, readout signals at low frequencies are similar to a square wave form, but for ED, signals appear only at edges of marks. This is why ED yields a small C value at low frequencies. At high frequencies, both SD signals and ED signals are similar to a sinusoidal wave form. Because ED signals are higher than SD signals are, ED has a higher C value at high frequencies.

To confirm the above computer simulation results, we made two disks: one for SD and the other for ED. For SD, the disk has a structure: polycarbonate substrate/ZnS–$SiO_2$ (128 nm)/$Ge_2Sb_2Te_5$ (20 nm)/ZnS–$SiO_2$ (35 nm)/Al alloy (150 nm). At $\lambda = 0.69\ \mu$m, it gives $R_a = 5\%$, $R_c = 33\%$, and $\phi_{\mathrm{ac}} = 30°$. For ED, the disk has a structure: polycarbonate substrate/ZnS–$SiO_2$ (172 nm)/Ge–Te (10 nm)/ZnS–$SiO_2$ (61 nm)/Al alloy (150 nm). At $\lambda = 0.69\ \mu$m, it yields $R_a = R_c = 20\%$ and $\phi_{\mathrm{ac}} = 90°$.

Figure 4 shows the experimental results for both the SD and the ED disks. Note that the p-p voltages and carrier

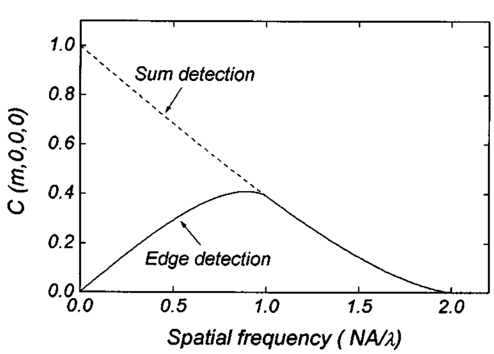


FIG. 2. $|C(m,0,0,0)|$ as functions of spatial frequencies for both sum and edge detection.

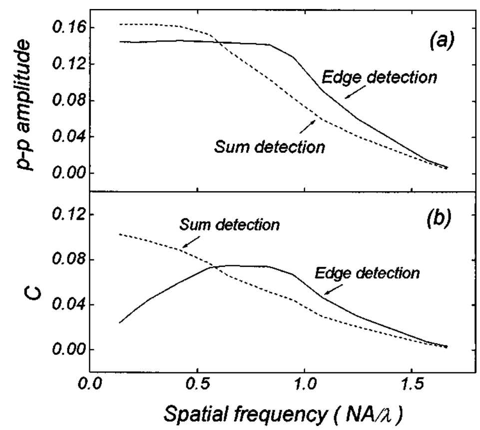


FIG. 3. (a) Peak-to-peak amplitude of signal and (b) its first harmonic, *C*, both as functions of data frequencies.

levels depend on the average reflectivity of the recorded track. For instance, the optical power of the reflected light from the disk containing a 5 MHz tone at the split detector was 56 $\mu$W for the SD disk and 36 $\mu$W for the ED disk. As expected, for the SD disk, the p–p voltages, carrier levels, and carrier-to-noise ratios (CNR) decrease with recording frequency. For the ED disk, the p–p voltages decrease with increasing frequency, but the carrier levels and CNRs first increase, then it decrease.

Comparing the SD signal with the ED signal, it is seen that, with increasing frequency, (1) SD p–p amplitude gradually decreases but ED p–p amplitude keeps a high level until the recorded marks are shorter than about 1.1 $\lambda$, (2) the carrier level difference and CNR difference between ED and SD increase. Particularly, the CNR value of the ED disk at the recording frequency of 11.7 MHz, corresponding to a mark length of 0.36 $\mu$m, is about 50 dB, which is much higher

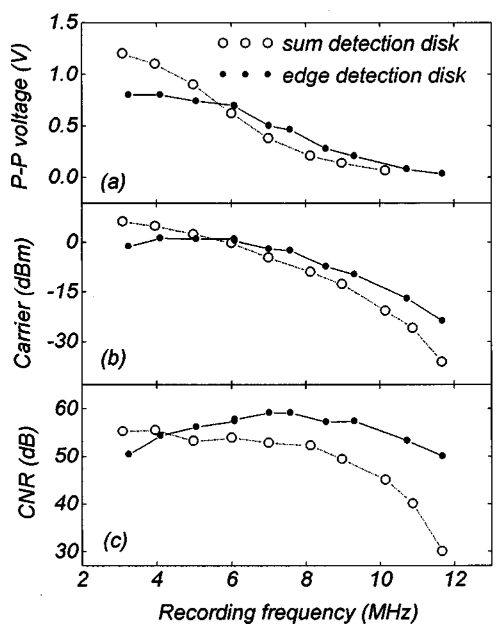


FIG. 4. (a) Peak-to-peak voltages, (b) carrier levels, and (c) CNRs vs recording frequency for the sum and the edge detection disks. In the read/write experiments, light wavelength $\lambda = 0.69\ \mu$m, the objective lens NA = 0.6, and the linear velocities of the disks = 8.5 m/s. For the measurements of the carrier level and CNR, the resolution bandwidth of the spectrum analyzer was 30 kHz.

than that of the SD disk. This higher CNR value for the ED disk results from both a higher carrier level and a lower noise level. (The thermal noise was only 2–3 dB below the observed noise floor at 11.7 MHz for the ED disk. With ideal preamplifiers, the CNR values would be 3 dB higher for the ED disk. For the SD disk, the total noise floor at 11.7 MHz is about 7 dB above the thermal noise levels.)

Land-groove recording is one of the ways to realize high density in optical data storage systems. In this scheme, which utilizes both land (L) and groove (G) for the recording of data, the land and the groove have equal widths, and the depth of the groove is chosen to yield minimum cross-track cross-talk.[1,2] For ED, the PC disk is required to have $\phi_{ac}\approx\pi/2$ for maximization of readout signal.[9] It is interesting to know if this phase shift affects the cancellation of the cross talk in the land-groove recording. For this purpose, we consider the worst case for the cross-track cross talk. In this case, a single tone data pattern is assumed to be on all of land tracks, we then read the disk by tracking on a groove. For the sake of simplicity, we assume that both land and groove are one λ wide, that marks and spaces are one λ long and one λ wide, and that the objective lens has NA=0.5. At the exit pupil of the objective lens, the field amplitude of reflected beam is an overlap of various diffraction orders. In the scalar approximation, the p–p amplitude, $\Delta P_e$, of the cross-talk signal for ED can be calculated as follows:

$$\Delta P_e = 0.112 R_c (0.42 + \cos\phi + \sin\phi), \qquad (2)$$

and, for SD, the p–p amplitude, $\Delta P_s$, of the cross-talk signal is

$$\Delta P_s = 0.0235(R_a - R_c) + 0.112[\sqrt{R_a R_c}\cos(\phi - \phi_{ac}) - R_c\cos(\phi)]. \qquad (3)$$

Here we assume that the incident beam is uniform and that $\phi = 4\pi d/\lambda$ is the phase difference between the light reflected from the land and that from the groove (d is the depth of groove). If, instead of a groove, a land is being read by the beam (i.e., the periodic data pattern is on the groove), then in Eqs. (2) and (3) $\phi$ must be substituted with $-\phi$.

In Eq. (2), $\Delta P_e$ depends differently on the depth of groove whether the track under consideration is a land or a groove. Figure 5 shows the computed cross-talk ratio for ED. The minimum cross talk occurs at different groove depths for land and groove. This means that the cross-talk level behaves differently when a land or a groove track is being read and that an optimum groove depth does not exist for ED disks for full cancellation of the cross talk in the scheme of land-groove recording. Another scheme needs to be utilized for edge detection. For SD, the situation is the same if $\phi_{ac}\neq 0$ or $\pi$, as seen in Eq. (3). However, for SD, if the disk is designed to have $R_a \ll R_c$, then a small $\phi_{ac}$ value will not cause much difference in $\Delta P_s$ while reading a land or a groove.

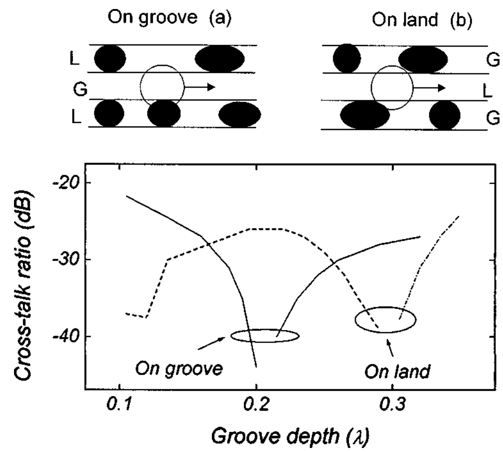


FIG. 5. Configurations for calculating the cross talk on groove (a) and on land (b) and cross-track cross-talk ratio vs groove depth in the scheme of edge detection. In (a) and (b), the focused beam reads the erased central groove (land) when the adjacent land (groove) tracks contain a random data pattern. In these calculations, land (groove) width=0.74 μm, light wavelength λ=0.65 μm, objective lens NA=0.6, phase difference $\phi_{ac}=\pi/2$, and mark width=0.8λ.

In summary, phase-change optical edge detection eliminates the dc level, enhances the data readout, and produces a high degree of contrast. It possesses a high CNR in the spatial frequency range where the carrier is meaningful for ED. However, because ED requires $\phi_{ac}\approx 90°$, there is no optimum groove depth for the elimination of the cross track cross-talk in the scheme of landgroove recording.

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[11] The computer program DIFFRACT is commercially available from MM Research Company, Tucson, AZ 85718.