201 GB/IN^2 RECORDING AREAL DENSITY ON SPUTTERED MAGNETIC TAPE

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I. INTRODUCTION

Magnetic tape systems are currently the most cost effective solution for the storage of large volumes of infrequently accessed data. However, for tape systems to remain competitive, it is essential to maintain this cost advantage by continuing to scale areal density. State of the art commercial linear-tape drives operate at an areal density of 5-7 Gb/in2. In this work, we demonstrate the viability of continuing to scale the tape roadmap for another decade [1] by performing a single-channel tape areal density demonstration of 201 Gb/in2 on a prototype sputtered magnetic tape.

II. TECHNOLOGIES AND EXPERIMENTAL RESULTS

The linear tape recording performance of a prototype perpendicularly oriented sputtered tape sample was investigated using a 48 nm wide tunneling-magnetoresistive (TMR) hard disk drive read head and a prototype tape write head. The sputtered tape media has a structure depicted in Fig. 1 that consists of the following layers: a diamond-like carbon (DLC) overcoat (5 nm), a CoPtCr-SiO_2 magnetic layer (14 nm), a Ru intermediate layer consisting of two films formed under different sputtering conditions (#1:18 nm/#2:5 nm), NiW (10 nm)/TiCr (2 nm) seed layers, and a CoZrNb (14 nm) soft under-layer deposited onto a polyaramide substrate. The surface roughness measured by AFM over 30 μm^2 is characterized by an average roughness Ra = 0.9 nm and a ten-point average roughness Rz = 16 nm. The average grain size in the CoPtCr-SiO_2 recording layer is 6.6 nm with a standard deviation of 1.2 nm. The magnetic properties, measured using Kerr magnetometer are: coercivity = 3880 Oe, Mrt = 0.57 memu/cm^2, and squareness = 0.97. The coercivity of the prototype media is larger than that of commercial tape and provides a room temperature thermal stability: K_uV/k_BT = 67.7, measured using the technique described in [2]. In order to fully saturate the media, we used a prototype ring-type tape writer with $Ni_{45}Fe_{55}$ poles and an additional 200 nm layer of Fe_xCo_{1-x} deposited between the 160 nm write gap and the trailing edge pole. This high B_s layer enables the production of larger write fields and provides sharper field gradients.

To explore the recording potential of the sputtered media, we recorded a repeating 255-bit pseudorandom binary sequence (PRBS) at linear densities from 569 kbpi to 900 kbpi using the prototype tape writer and a reel-to-reel tape transport. The recorded PRBS data was read back using a 48 nm wide hard disk drive TMR read head and the captured waveforms were processed by a software read channel that implements all the functions of an in-drive read channel. We set a target threshold error rate performance based on our previous work in which we analyzed the performance of iterative decoding of a product Reed-Solomon code with N1 = 240, N2 = 192 and a code rate of 0.83, similar to the codes implemented in current commercial tape drives [3]. In this work we found that with a byte-error rate (BER) of ≤ 4.5e-2 at the output of the detector a user error rate of less than 1e-20 can be achieved after two consecutive C1 and C2 decoding steps. Hence we set a performance target of a raw byte-error rate of < 4.5e-2 at the output of the detector, assuming a reverse concatenation architecture. The BER performance of the read-back waveforms was analyzed using four detection algorithms: 1) 8-state extended partial-response class 4 (EPR4) detection, 16-state noise-predictive maximum-likelihood (NPML) detection, 16-state data-dependent NPML (DD-NPML) detection and 4) and an extended version of the DD-NPML detector that tracks the mean of the data-dependent noise (D3-NPML). Figure 2(a) depicts the channel SNR versus linear density at the input of the EPR4 detector and Fig. 2(b) compares the BER performance of the four detectors. At a linear density of 818 kbpi the channel SNR is 10.7 dB and the BER performance of all four detectors is below the target of less than 4.5e-2. The best performing detector, D3-NPML, crosses the BER target at an interpolated linear density 893 kbpi where the

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channel SNR is estimated to be 9.9 dB. Hence, an operating point of 818 kbpi in combination with the D3-NPML detector provides an operating margin of about 0.8 dB.

To explore the potential track density achievable with this media we performed track-following experiments using an experimental low noise reel-to-reel tape transport and a prototype TMR tape read head equipped with two, 1-μm-wide servo readers mounted in a commercial tape head actuator. The media was formatted with an experimental timing-based servo pattern with a 24° azimuth angle and a 51 μm sub-frame length that enables the generation of servo estimates at a high rate and nano-scale position estimation resolution. The read-back signals from the two servo readers were processed using a pair of synchronous servo channels implemented in an FPGA-based prototyping platform. The position estimates from the two servo channels were then averaged and used for feedback control. An H_∞-based track-following controller was implemented in the same FPGA to enable real-time closed-loop track-following experiments. The control loop hardware and FPGA implementation were optimized to reduce delay in the control system and enable the synchronous operation of the controllers. Because of the speed dependence of both the delay in the servo signal and the frequency characteristics of the lateral tape motion, a set of track-following controllers were designed with each controller optimized for a specific tape speed. The low estimation noise in the averaged estimated position signal enables the use of high-bandwidth track-following controllers characterized by a closed-loop bandwidth derived from the sensitivity transfer function that ranges from approx. 478 Hz at 1.2 m/s tape speed to approx. 1380 kHz at 4.1m/s tape speed. Figure 2(c) shows an example of the closed-loop position-error signal (PES) measured at a tape speed of 3.1 m/s. Figure 2(d) depicts the standard deviation of the PES (σ-PES) as a function of tape velocity demonstrating a σ-PES $\le$ 6.5 nm over the speed range of 1.2 to 4.1 m/s. The minimum reliable track width can be estimated using the model described by the Information Storage Industry Consortium [1] as: track width = $2\sqrt{2}$ *$3\sigma_{PES}$ + reader width. Taking a reader width of 48 nm and the worst case measured σ_{PES} = 6.5 nm leads to an estimated track width of 103 nm and a track density of 246.2 ktpi. Combining this track density with the linear density of 818 kbpi achieved within the error rate target with the 48 nm reader corresponds to a potential areal recording density of 201.4 Gb/in^2.

REFERENCES

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2) J. Tachibana et al. IEEE Trans. Magn., vol. 50, 3202806, 2014
3) S. Furrer et al. IEEE Trans. Magn., vol. 51, 3100207, 2015

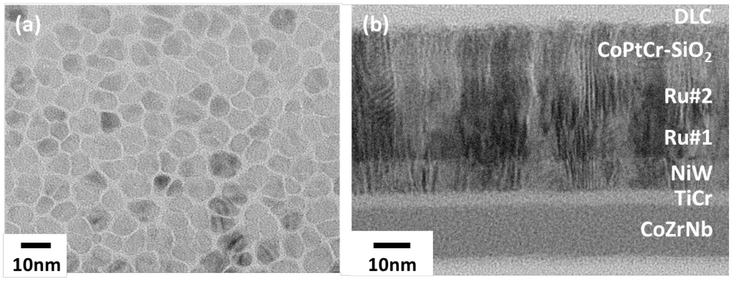

Figure 1 (a) TEM Plan view and (b) TEM cross-section images of the prototype sputtered tape media.

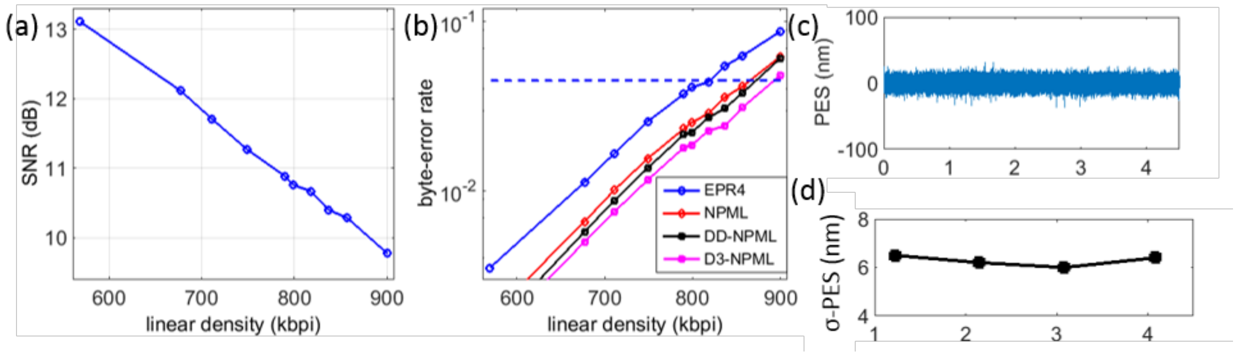

Figure 2 (a) Data channel SNR and (b) byte-error rate versus linear density. The dashed line shows the demo byte-error rate target. (c) PES during track following at 3.1 m/s. (d) Standard deviation of the PES versus tape speed.