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Flexible Magnetic Reading/Writing System: Heat-Assisted Magnetic Recording

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Abstract

Data storage is one of indispensable technical assets defined in a frame work of Industry 4.0. Among many data storage technologies, inherent magnetic data storage on surfaces of technical components is promising, especially when the components are employed in harsh environments. Comparing with other storage technologies like labels, RFID tags and engraving, the inherent magnetic storage is rewritable and resistant to weathering. High temperature and a high magnetic field, however, can degrade or even delete magnetically stored data. This limitation can be coped with using a medium with higher coercivity that can withstand external magnetic fields and high temperature. As a consequence of higher coercivity, a higher write field is required to magnetize the medium. A design of a flexible write head that is suitable for storage applications on surfaces of technical components, is restricted by head-medium interface criterions, and hence field strength generated from the write head cannot be arbitrary large. To solve this problem, a heat-assisted magnetic recording (HAMR) is proposed as a means to temporarily reduce coercivity of a medium during writing. A realization of a HAMR module and an experiment as well as its positive results are presented in this work.

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Keywords: Heat-assisted magnetic recording (HAMR); flexible substrate; magnetic write head; inherent magnetic data storage; Industry 4.0

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1. Introduction

Industry 4.0 (I4.0) exhibits three aspects for future industrial production: a new level of organization and control of value creation chains throughout product life cycle, availability of all relevant information in real-time using links between entities in the value creation chain and creation of optimal real-time changeable and self-organizing value creation chains. One important integral part of I4.0 is the technical assets, defined as an artifact intended and created for a specific role in a system. They are one of reference models used in a framework of I4.0 [1] and reside in the asset layer of the reference architecture model industry 4.0 (RAMI 4.0) [2]. Among many technical assets, data storage is physical fundamentals of information integration and communication in the I4.0. In this work, heat-assisted magnetic recording on surfaces of technical components is presented. It is a part of inherent magnetic data storage technology developed in a frame work of Collaborative Research Center (CRC) 653 “Gentelligent Components in Their Lifecycle”.

Similar to technology used in hard disk drives, main components of magnetic data storage systems are a magnetic medium and a read/write head. The medium in our case is magnesium alloyed with cobalt hard magnetic particles, of which components or parts of components can be made [3]. Development and use of our inductive write heads and its flexible variations can be found for example in [4-7]. It should be noted that a particular difference between our system and hard disk drives is an environment where the systems are operated. Write heads and magnetic platters of hard disk drives are encapsulated in an enclosure and operated in a controlled environment, so that temperature, external magnetic field interference and vibration are under designed values. In contrast to that, the medium of our system (a component), for example a wheel carrier, is used in an uncontrolled environment. Inevitably, the medium could experience high temperatures and magnetic stray fields, which can directly affect and deteriorate data stored in a medium. To deal with this, a medium with high stability or, in other words, a medium with high coercivity H_c should be used. However, high coercivity means high write field, whose maximum strength is limited by a design and a soft magnetic material used in a fabrication of a write head. A brilliant solution to usage of high coercivity media is to temporarily reduce their H_c during the write process by means of energy-assisted techniques [8]. Among many techniques, heat-assisted magnetic recording (HAMR) shows high potential and is actively studied by many researchers from the hard disk drive domain [9].

Nomenclature

d	distance from the secondary principal point of the first lens to the primary principal point of the second lens
f_1, f_2	focal length of the first and the second lens
H_c	magnetic coercivity (A/m)
s'_2	image distance, a distance from the secondary principal point of the second lens to a focal point
w_0	beam waist, diameter of a focal point

2. HAMR module

A study of heat-assisted magnetic recording (HAMR) on surfaces of technical components starts with realization of a HAMR module by integration of a heat source into a flexible write head. A laser module, Nano250 Series from Qioptiq, is employed as a heat source. The laser module can emit a collimated 532 nm green continuous wave (cw) laser beam. The laser module as well as the flexible write head is mounted on an optomechanical rail system as shown in Fig. 1. A micrograph of the air gap of the flexible write head is shown in the lower right of Fig 1a. Its length and width are 50 µm and 100 µm respectively. In order to align and focus a laser beam through the air gap of the flexible write head, a lens system is placed between the laser module and the write head. The lens system consists of two plano-convex lenses. One is mounted on a carrier of the rail system and adjustable in z-direction. The other is mounted on a XY translation module and freely adjustable in x-, y- and z-direction. A beam trace is depicted in a simplified layout in Fig. 1b. Note also a focal plane on the right, where the laser beam passing through the air gap is focused on.

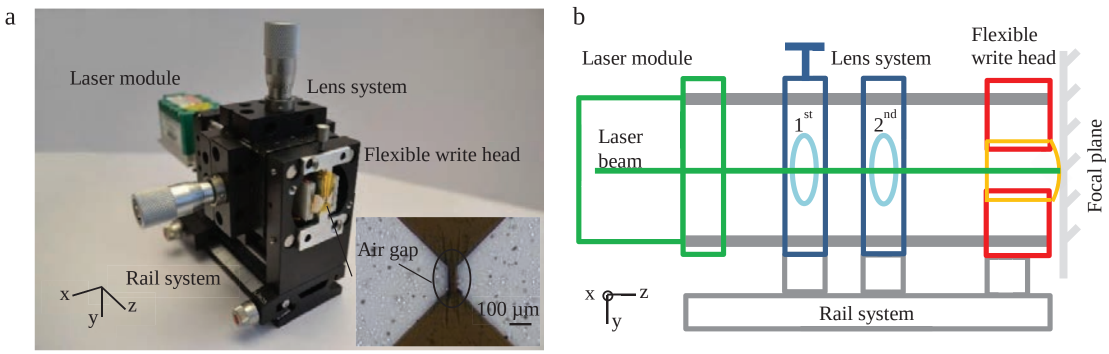

Fig. 1. (a) heat-assisted magnetic recording module for inherent data storage on surfaces of technical components; (b) simplified layout

Next, two important parameters of the HAMR module are determined, namely an image distance of a laser beam focusing through a lens system and a corresponding beam diameter at a focal point. Assuming that the laser module emits a perfectly collimated beam, thus the first parameter, the image distance s'_2, can be calculated using the following equation [10].

$$s'_2 = \frac{f_2\left(f_1 - d\right)}{\left(f_1 + f_2 - d\right)} \tag{1}$$

Alternatively, the WinLen3D Basic, a free version of WinLen3D offered by Qioptiq, can be used to ease calculation of the image distance [11]. In fact, with precise lens positioning, only one lens is adequate to define the image distance in the z-direction. Using two lenses, however, reduces precision constraint in positioning the lenses. This is a result of a scaling effect implied by the *d* parameter in Eq. 1. For example, in our configuration, if a distance between the lenses (*d*) is changed by 1 mm, the image distance is changed only by 0.37 mm, resulting in a 2.70 scaling factor. The second parameter, the focal point diameter or the beam waist w_0 of the focused laser beam, defines an attainable data bit size. A measurement of w_0 is performed using Spiricon Model LW230 beam profiler, by careful tracing of the focused beam using a XYZ translation system as shown in Fig. 2a. The profile of the focused beam is presented in Fig. 2b. To end this section, a parameter summary of our HAMR module is given below in Table 1.

Table 1. HAMR module

Parameter	Value
Qioptiq Nano 250 Series laser module	λ 532 nm, collimated TEM_{00}, ø 1.4 mm, max 220 mW
Rail System	10 cm flat sliding rail
Lens	Plano-covex, f 50 mm, N-BK7, ø 25 mm
XY translation module	± 1 mm in both x- and y-directions
Image distance	20.30 mm
Focal point diameter at image distance	$ø_x$ 36 µm, $ø_y$ 36 µm at 220 mW nominal power
Flexible write head	NiFe core on polyimide, B_s 0.67 T
Air gap	50µm length by 100 µm width

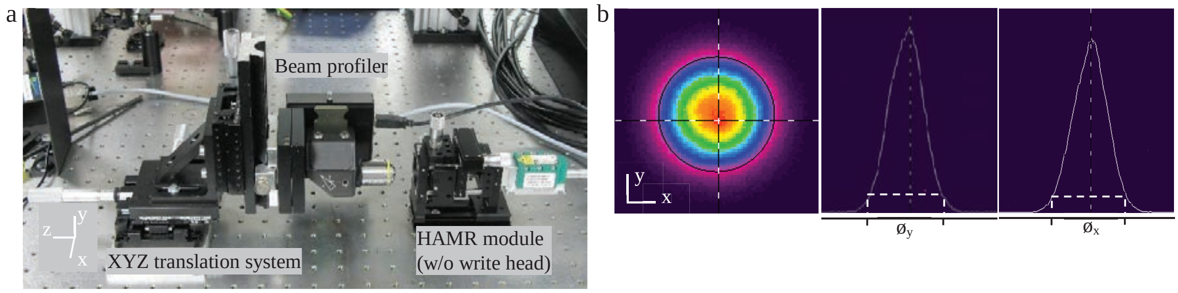

Fig. 2. (a) beam profile measurement; (b) profile of a focused beam emitted from a laser module operated at 220 mW nominal power

3. HAMR experiment

Positioning of a laser beam through an air gap of a flexible write head is the first task in a HAMR experiment. The HAMR module discussed in section 2 is mounted on a precision XYZ translation stage developed in-house. The configuration of the experimental system is depicted in Fig 3. The stage is equipped with stepper motors and can be driven in x- and z-direction with 4 µm step resolution. Due to the configuration of the HAMR module, a direct alignment using a photodiode is possible and, in our case, a standard photodiode, BPW 34 from Osram is employed. The photodiode is mounted on a write plane of the precision XYZ translation stage, which is normal to the z-direction as show on the top right of Fig. 3. The head poles of the flexible write head are brought into contact with the photodiode by driving the precision XYZ translation stage in z-direction. The contact region is marked with an ellipse. Positioning the laser beam is done in two steps. The first step is focusing the beam on a focal plan, which is an interface between head poles and a medium (or a photodiode during an alignment process). A close-up image of the focal plane is placed at the bottom right of Fig. 3. An image distance from the focal plane to the second principle point of the second lens is adjusted and measured. Then a distance between the first and the second lens is calculated using Eq. 1 in section 2. The second step is aligning the focused laser beam through the air gap. Fig. 4a illustrates cross section model of the flexible write head and reveals a through hole, through which the focused laser beam passes and reaches the air gap at the bottom of the head. A region near the air gap can be scanned using the beam by manipulating the XY translation module of the lens system. An electrical signal from the photodiode decreases or increases whenever the focal point is blocked by the head poles or exposed to the photodiode respectively. Using this information, a position of the air gap can be determined and used to align the beam. A schematic procedure for the beam alignment is illustrated in Fig. 4b. For example, the region near the air gap is scanned in y-direction to find coordinates of points where the electrical signal changes occur. A y-coordinate of the air gap is at halfway between those points.

Because the flexible write head is fabricated on a polyimide substrate that absorbs laser beam, an additional step is required in order to create an opening in the polyimide substrate in the air gap region. This can be easily done after laser beam positioning by increasing laser power to a level that melts the polyimide substrate. Additionally, a raster scan in the region of the air gap can be performed to ensure an adequate opening.

An IEC I/Type I cassette tape is selected as a storage medium for HAMR experiment. The medium coercivity is 30 kA/m which is comparable to our target storage medium (20-32 kA/m). The tape is attached on a dummy component. Data tracks consist of a 101010… bit pattern is written in x-direction. For cool writing, different bit lengths are written to create reference data tracks. For heat-assisted writing, the bit length is set to 100 µm, which is long enough to clearly identify a transition region between a ‘1’ and a ‘0’ bit. The strength of a write filed is decreased to a lower level and tested to ensure that magnetization of the medium solely by the write field is not possible. During a write process, the head poles are in contact with the medium and the laser module is configured to output a continuous wave laser beam at 80 mW nominal power.

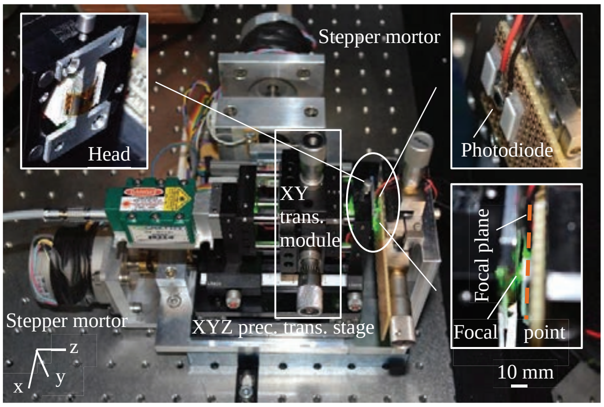

Fig. 3. positioning a laser beam on a medium using a precision XYZ translation stage and a XY translation module of the lens system

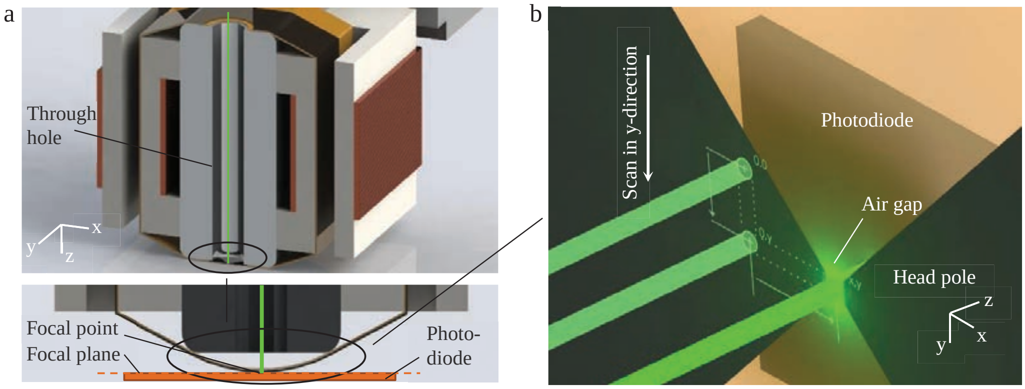

Fig. 4. (a) a cross section model of a write head; (b) schematic procedure for aligning a laser beam through an air gap using a photo diode

4. Results

An opening through a polyimide substrate is marked with an ellipse in Fig. 5. The opening was not perfectly centered in the middle of an air gap which is a result of an inaccurate raster scan done manually. Better scanning technique could be utilized to improve the result, but it is not necessary as long as the opening is large enough for a focused laser beam to pass through. Note also that the right head pole was not damaged by misalignment and thus the performance of the head was not affected. A micrograph of heat tracks resulted from writing experiments on an IEC I/Type I cassette tape is given in Fig. 6. After writing the first track, the head flew above the medium and landed on the second track. There is no need to reposition the beam before writing the second track because the air gap of the flexible write head can adapt itself to the surface of the medium. A reference spot is made at the beginning of a track for a purpose of track identification.

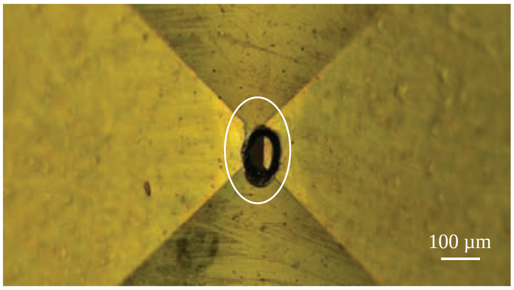

Fig. 5. an opening created by a focused laser beam using a raster scan

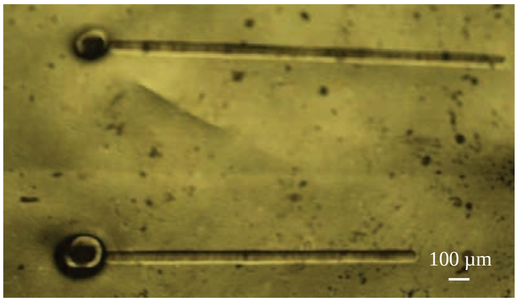

Fig. 6. two heat tracks on an IECI/Type I cassette tape; note also unevenness of the medium and the reference spots at the beginning of the tracks

Magnetic data tracks were made visible by means of a magneto-optical faraday effect and shown in Fig. 7. Those micrographs were taken using a polarized light microscope, that is equipped with a magneto-optical sensor (bismuth-substituted yattrium iron garnet, Bi:YIG). An examination of the reference tracks in Fig. 7a indicates an attainable data bits magnetized in cool write process. The data bits have rectangular shape and their transition regions have a size comparable to the size of the air gap (50 µm length by 100 µm width). For heat-assisted writing, it can be clearly seen from Fig. 7b that data bits have circular shape and their transition regions have an approximate diameter equal to 36 µm. This is corresponding to a diameter of a focused laser beam at a focal plane. An increasing data density can be estimated from a ratio of the rectangular transition size to the circular transition size, which is 4.9. Since the heat tracks are furrowed into the medium, a contact between the medium and the magneto-optical sensor is not perfect. As a consequence, some data bits were blurred.

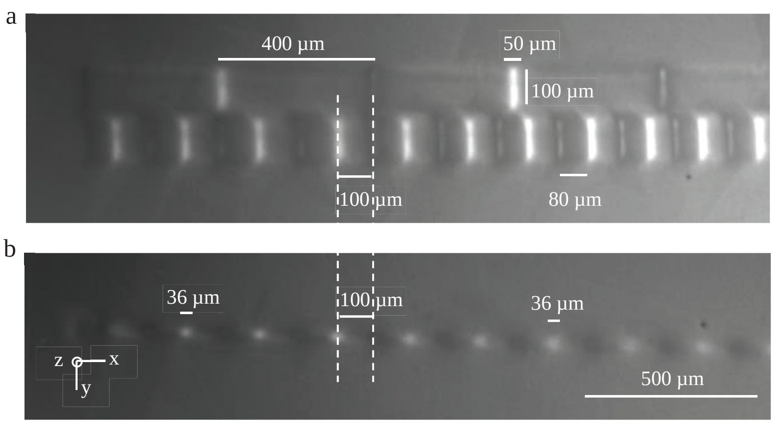

Fig. 7. (a) reference data tracks created by cool writing; (b) a data track created by HAMR

5. Conclusion

A heat-assisted magnetic recording (HAMR) for inherent data storage on surfaces of technical components is presented. Heat is exploited in a write process to temporary reduce coercivity of a medium. A realization of a HAMR module is done by integration of a laser heat source into a flexible write head. Focusing and aligning a laser beam are described. A HAMR experiment was performed on a medium with coercivity of 30 kA/m and positive results were obtained. Transition regions of data bits magnetized this way have circular shape corresponding to a diameter of a focused laser spot employed during writing. Therefore, the successful HAMR experiment is confirmed. Further examination will be done in order to better understand effects of heat and a magnetic field as a combined source for magnetization of a medium.

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