Using CD-Recorder to Fabricate Microfluidic Laboratory-on-a-CD Systems on CD-R

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Abstract: This paper describes the potential use of dye-decomposing nature induced by CD-Recorder laser beam, which is utilized to encode digital information on CD-R media, to fabricate microfluidic laboratory-on-a-CD systems. Different from conventional methods, such as CNC-machining and photolithography techniques used for prototyping, and also various molding methods adopted for mass production, the use of CD-Recorder to fabricate laboratory-on-a-CD provides a simple and intuitive approach. For demonstrating the patterning capability of CD-Recorder here, on the same piece of CD-R, outer layer patterned with microfluidic structures selected from the published laboratory-on-a-CD devices for enzymatic assay; inner layer encoded with digital information, represented by a piece of music, implies its potential integration in automatic control of analytical procedures and programmatic data analysis. Since the duration necessary for producing a piece of laboratory-on-a-CD using CD-Recorder is less than 20 minutes, it shows advantageous in fast prototyping. Although current CD-Recorder and CD-R, is initially designed for storing digital information, however, in addition to photolithography and soft lithography, it could be modified to accommodate our proposed alternative function to fabricate microfluidic systems.

Key-Words: CD-Recorder, CD-R, Microfluidic systems, LabCD (Laboratory-on-a-CD), μTAS (Micro Total Analysis System), Fast prototyping

1 Introduction

1.1 Lab-on-a-Chip

The concepts of ”lab-on-a-chip”, also referred to miniaturized micro-total analysis system, was ideally proposed to carry out a complete analysis such as sampling, sample pre-treatment, reaction, separation, detection, product isolation, and data analysis on the same platform in an integrated and automatic manner [1]. As early as 1970s, Stephen Terry miniaturized a gas chromatography system on a silicon wafer [2]; however, his work was unnoticed till Andreas Manz’s conceptual μTAS paper published in 1990s [3]. Originally, the main reasons for miniaturization was to improve the analytical performance of the device rather than to reduce the size, however, the miniaturizing was eventually recognized as showing advantages in design flexibility, economic use of reagents, decreased requirements for power, increased speed of analyses, and portability, besides of simple size reduction [4]. In the design and fabrication of lab-on-a-chip, microfluidic system based on the capillaries with dimensions of 10-1,000 μm in width to transport and manipulate the samples and reagents in minimized quantities is essential [5]. For controlling the flow of small volume liquid in microscopic channels, the fabrication of the appropriate pumps, valves, and mixing elements is necessary. Until now, there have been various miniaturized chemical and biochemical devices designed in the version of lab-on-a-chip, including miniaturized separation systems, micro-reactors, micro-arrays, and combinations of these components [6]. These devices found their broad utilization as the tools for chemistry and biochemistry systems in fundamental research and various analytical applications [7].

1.2 Lab-on-a-CD

“Lab-on-a-CD” is to integrate all the microfluidic structures and analytical devices required to complete an analysis on a circular plastic compact disk. It is an alternative approach in the miniaturizing trends to fabricate microfluidic

lab-on-a-chip systems. There have been varieties of lab-on-a-CD studies for ion assays [8,9], multiple enzymatic assays [10], DNA microarray [11], immunoassay microarrays [12], and gas sensor [13], etc. In addition to the electrokinetic control methods in microfluidic system that has received the most attention, the centrifugal force can also be utilized alternatively in the setup of lab-on-a-CD [8,9,10]. Since centrifugal force could be generated by the rotation of a simple motor. Also, it is safe and has lower power and space requirements. Compared with electrokinetic control, it is relatively insensitive to the chemical properties of the building materials; therefore, it can work over a range of ionic strengths and pH values. Combining with the design of numerous active and passive valves, the flow of liquid confined in sealed microfluidic channels can be effectively gated in a centrifugal microfluidic system with the control of motor spinning speed. Furthermore, optical detection can also be integrated to obtain signals from pre-specified positions on the CD, since the polymers, such as PC (polycarbonate), PMMA (polymethylmethacrylate), PDMS (polydimethyhiinxane), and PS (polystyrene), etc., can be optically transparent to efficiently transmit excitation and emission radiation to and from the sample within the CD [14]. Besides, laser diodes present in many devices that read CD, including CD-ROM drives and DVD players, can be utilized as the excitation light sources in optical detection. Since laser diodes are amenable to miniaturization. Of which the system does not require additional optics to provide monochromatic radiation and does not require high voltage power supply. Thereby, laser diodes and fluorescence detection are more compatible with the CD platform. This makes microfluidic lab-on-a-CD platform more suitable to portable CD player setup [9].

1.3 Methods for Fabricating Lab-on-a-CD

To construct lab-on-a-CD, a number of fabricating techniques for polymer-based CD microfluidic platforms have been proposed [15]. For prototyping, traditional CNC-machining (Computerized Numerically Controlled-machining) and photolithography techniques were used. To test the performance of newly design microfluidic devices, the fast and cost-effective prototyping methods are required. CNC-machining can be easily used to produce the device mechanically and can be used in various materials such as metal, glass, and plastics. However, the using of CNC-machining could not provide smooth surface finish, high aspect ratio, and good dimension control. It usually takes several hours to make a single CD platform. Photolithography shows the advantages of high aspect ratio and small feature size, as well as the relevant techniques were highly developing and available. In spite of these time-consuming, expensive cost and technically difficulties are the major disadvantages of photolithography. For mass production, various molding methods including casting, injection molding, and hot embossing, using mold inserts made by CNC-machining or photolithography, were studied. The selection of appropriate mass production techniques will help to reduce the cost and make microfluidic systems acceptable in practical application. Casting shows the advantages in simple processing and low tooling cost, but shows the disadvantages in the needing long cycle time (minutes to hours), less dimensional control, little automation and contamination in some resin residue. It can be used for fast prototyping and low volume production. Injection molding is good for producing small features with low aspect ratio, short cycle time in processing (minutes), high automation, and excellent dimensional control; nevertheless, the high tooling cost is the drawback, even though it can be employed for large volume production. Hot embossing is good for small features, simple processing, medium cycle time (minutes) and low tooling cost. Conversely, it is disadvantageous in difficulty for high aspect ratios, difficulty for multiple depths, less dimensional control, little automation, and only good for planar features. Nevertheless, it can be adopted for low and medium volume production of microfluidic systems.

1.4 Noval Method for Fabricating Lab-on-a-CD

In this paper, we propose a new approach, to fabricate microfluidic lab-on-a-CD systems on CD-R by using CD-Recorder. Unlike the general approaches in making lab-on-a-CD, the current method adapts laser beam-induced dye decomposition methodology in CD-R currently used to store digital information based on the formations of pits in dye layer of CD-R. The microsystem thus made might be potentially applicable to fabricate miniaturized system. For demonstration in this work, the regular microstructures with different channel width in micrometer scale and the laboratory-on-a-CD devices for enzymatic assay [10] were patterned on CD-R using CD-Recorder.

2. Materials and Method

The CD-Recorder CRW-F1 CD Recordable/Rewritable Drive was purchased from Yamaha KHS Music Co., Ltd. (Taipei, Taiwan), and equipped in desktop personal computer with Pentium II-class or higher CPU, 32 MB or more RAM, and 50 MB to 100 MB of free space as a working area on the hard drive. The Laser information of the Yamaha CD-Recorder CRW-F1 CD Recordable/Rewritable Drive is as following: Laser Product Class is Class 1; Laser Diode Wavelength is 779-789 nm; Pulse Durations and Max. Output in Write Mode is Max. 62 mW (Max. Cycle 111 ns, Min. Cycle 30 ns at Max. Speed). The CD-R was purchased from Lead Data, Inc. (Hsinchu, Taiwan). The CD-Recording software Nero 5.5.8.13 was from Ahead Software AG (Karlsbad, Germany). The Disc@2 function of CD-Recorder is utilized to pattern the regular microstructure graphs and the laboratory-on-a-CD devices for multiple enzymatic assays [10] on CD-R, accompany with the encoding of digital information on CD-R just like the CD-Recorder usually does. The PC scanner PowerLook III was purchased from UMAX Data System, Inc. (Taipei, Taiwan). For capturing better quality images, we took the pictures of patterned CD-R by using PC scanner instead of digital camera for escaping from the serious effects of light reflecting. The Microscope Olympus BX40 UV-Visible Video Microscope was obtained from Olympus Optical Co. Ltd. (Tokyo, Japan). The digital camera Coolpix 995 was purchased from Nikon Corporation Imaging Company (Tokyo, Japan). The patterned CD-R would be characterized using phase contrast microscope and its pictures were taken by digital camera.

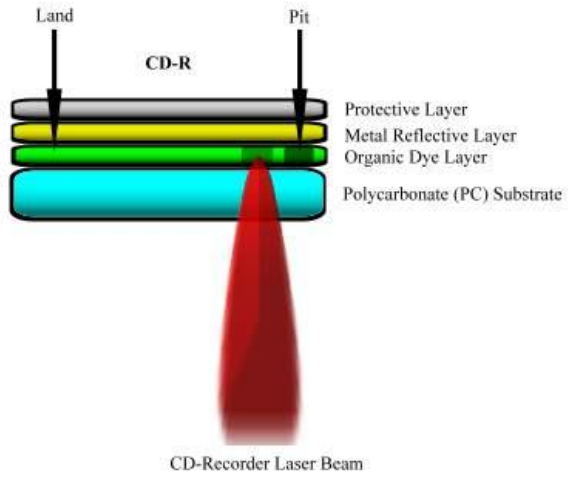

Fig. 1. Schematic illustration of structures of CD-R and effect of laser recording on CD-R using CD-Recorder. CD-R, the representative optical recording medium, mainly consists of different layers such as a polycarbonate (PC) substrate, an organic dye layer, a metal reflective layer, and a protective layer (UV-cured resin overcoat). Decoded on CD-R, digital information can be defined, by pits formation or not, by CD-Recorder laser beam-induced dye decomposing. For storing digital information, the smallest pits on CD-R can be less than 1 μm.) The diagram part is not in proportion.

3. Results and Discussion

3.1 Recording on CD-R by CD-Recorder.

Because of the large storage capacity, high fidelity and low cost, organic dye-based CD-R has become one of the dominant digital information storage media since the development by Taiyo Yuden in 1989. The multilayered structure of an organic dye-based CD-R and the effect of laser beam recording using CD-Recorder are shown in Fig. 1. The CD-R, fabricated by simple spin coating process, typically consists of different layers, including a polycarbonate (PC) substrate, an organic dye layer, a metal reflective layer, and a protective layer (UV-cured resin overcoat). The CD-Recorder laser beam is incident on the disk from the polycarbonate substrate side. It has a wavelength of 780 nm with a Gaussian radian profile and an exp (-1) power radius of 0.6 μm [16]. For recording the digital information on CD-R, the energy of CD-Recorder laser beam results the thermal decomposition of organic dye into "pits," whose smallest pit size can be less than 1 μm, and the other dye areas without being decomposed by CD-Recorder laser beam are regarded as "lands." Most dyes for optical recording media have decomposition temperature higher than 200 ℃, and do not decompose easily in a low writing power range.

3.2 Patterning on CD-R by CD-Recorder.

For demonstrating the potentials to extend the CD-Recorder laser beam-induced dye decomposing ability on CD-R from storing digital information, based on lands and pits with smallest ones in the scale less than 1 μm, into fabricating microfluidic system, based on capillaries with lateral dimensions in 10-1000 μm. The regular microstructures in micrometer scale patterned on CD-R using CD-Recorder are shown in Fig. 2 through phase

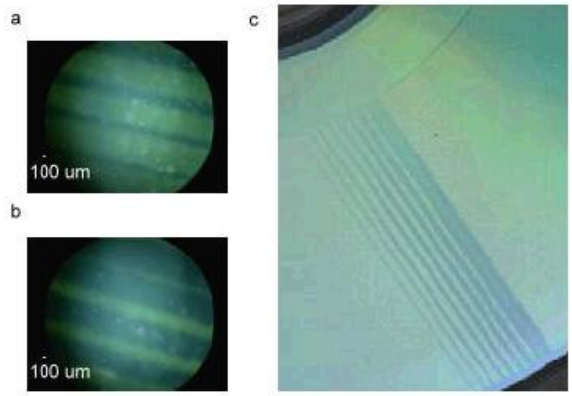

Fig. 2. The phase contrast images and PC scanner images of regular patterns on CD-R using CD-Recorder. The widths of patterned regular glooves on CD-R are 100 μm-900 μm. (a) The phase contrast images of patterned regular microstructures with width of 100 μm, 200 μm, 300 μm, and 400 μm, individually. (b) The phase contrast images of patterned regular microstructures with width of 600 μm, 700 μm, 800 μm, and 900 μm, individually. The phase contrast images were taken by using digital camera through the phase contrast microscope. (c) The PC scanner images of patterned microstructures with width of 100 μm to 900 μm. For decreasing the effects of light reflecting and improving the quality of image capturing, image was taken by using PC scanner but not digital camera.

contrast microscope and PC scanner. The widths of patterned regular microstructures, the shadow parts are the areas whose dye layers undergoing decomposition by CD-Recorder laser beam, fabricated on CD-R are 100 μm to 900 μm. Fig. 3 is the PC scanner image that demonstrates the imprint microfluidic structures and digital information on the same CD-R platform using CD-Recorder. Encoded on inner layer of CD-R, a piece of music, 'Air', from the "Water Music Suite" composed by the famous baroque musician George F. Handel (1685-1759) was selected as the demonstration of digital information, which potentially implies the imprinting of the programmatic controlling/operating of analytical process and the automatic recording/analyzing of analytical data from the microfluidic structures. Patterned on outer layer of CD-R, the laboratory-on-a-CD analytical devices for multiple enzymatic assays [10] was chosen to demonstrate the microfluidic structures patterning here. The fabrication method used in microfluidic lab-on-a-CD platform for ion-selective detection was constructed via CNC-machining of an architecture created in a CAD program into a 12 cm diameter disk of PMMA [8,9]. The one for multiple enzymatic assays was produced based on photolithography and casting of PDMS after designing in the CAD software [10]. Our results demonstrated the microfluidic structures patterns could be transferred to CD-R via CD-Recorder through CD-Recorder laser beam induced dye decomposition.

3.3 Fabrication of Lab-on-a-CD Using CD-Recorder.

Since the fabrication time of current method is less than 20 minutes, which shows the advantages in rapid prototyping to fabricate microfluidic system on CD-R using CD-Recorder. Due to the decomposition induced by CD-Recorder laser beam happens in dye layer of which positions between the polycarbonate substrate and the metal reflective layer. Therefore, no sealing process is required after fabrication of microfluidic structures. Besides, all the fabricating processes, including the encoding of digital information and the patterning of microfluidic structures, can be proceed in common settings without the needs of expensive equipment and clean room environment. In addition, the polycarbonate substrate, just like many of the other polymers materials used to make microfluidic system, can be optically transparent in the spectrum region of VIS absorbance and emission, as a result the microfluidic system in CD-R format is compatible with the optical detection systems, and also employed in portable CD/DVD players. Furthermore, it is compatible with current CD mass production processes after initial prototyping stages. Finally, the potential to integrate microfluidic structures and digital information on the same CD-R platform using CD-Recorder brings an interesting possibilities to realize in the field of miniaturized micro-total analysis systems. Although the dimension of fabricating microstructures on CD-R shown in this study focus on micrometer scale, however, the size of writing bits can be less than 40 nm has been demonstrated on commercialized CD-R [17]. There is plenty of room at the bottom, indeed. For better realization of miniaturized micro-total analysis system fabricated on CD-R using CD-Recorder, certainly the CD-R and CD-Recorder initially designed for being utilized in informatics industry should be modified and improved. However, the proposed method in this paper does present an alternate approach for fabricating microfluidic systems other than photolithography and soft lithography.

Fig. 3. The scanner image of centrifugal microfluidic lab-on-a-CD system for multiple enzymatic assays and digital information imprinted on CD-R using CD-Recorder. For demonstrating the potentials to integrate microfluidic structures and digital information on the same CD-R platform using CD-Recorder, patterned on outer layer, the microfluidic structure was chosen with the centrifugal microfluidic system design for multiple enzymatic assays [10]; encoded on inner layer, the digital information was demonstrated with a piece of music "Air" from the "Water Music Suite". Also, for decreasing the effects of light reflecting and improving the quality of image capturing, image was taken by using PC scanner but not digital camera.

4. Conclusion

The field of micro-systems is progressing rapidly. Various methods have been proposed to produce microfluidic lab-on-a-CD systems, including CNC-machining and photolithography for prototyping as well as casting, injection molding, and hot embossing for mass production. A novel fabrication technique, based on the using of patterning ability of personal computer CD-Recorder, has been investigated here. The microfluidic structures and digital information can be both

imprinted on the same platform in this approach. The microfluidic structures are patterned on outer layer and the digital information is encoded on inner layer of CD-R, which allows the controlling/operating of analytical process and recording/analyzing of analytical data automatically. In addition, using this method to fabricate miniaturized micro-total analysis system provides, but not limited to, following advantages: (i) rapid prototyping, (ii) cost effective, (iii) no vacuum environment required, (iv) compatible with current CD mass production process, (v) no sealing process (is) needed after fabricating, and (vi) can be employed in portable CD/DVD player, etc. Further modifications and improvements would be still desired for better performance of micro-system fabricated on CD-R by using CD-Recorder.

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