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Multi-wavelength operation of optical disk drives for chemical and biological analysis

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ABSTRACT

Optical disk drives have lasers that operate at 405, 650, and 780 nm making these devices attractive for a wide variety of analytical applications. Here we demonstrate the use of super audio compact disks (SACDs) and computer optical disk drives for multi-wavelength chemical measurements. As an example, dual-chemistry chlorine sensing films were formulated using combinatorial techniques and deposited onto SACDs. The chlorine response was measured at the analytical wavelength (780 nm), while thickness variations were normalized using the response at the 650-nm reference wavelength where the sensing films were not affected by chlorine exposure. Compared to a single-wavelength readout, this dual-wavelength approach improved the linear correlation coefficient (R^2) from 0.76 to 0.95 and the limit of analyte detection from 600 to 300 ppb. The use of multi-wavelength optical disk drives should enable chemical and biological sensing with the expanded diversity of sensing chemistries and the advantages of multi-wavelength spectral processing.

1. Introduction

The installed base of compact disk (CD) and digital video disk (DVD) players and computer optical disk drives exceeds 600 million and there are over 200 billion optical disks that can be played in these devices [1,2]. These widely used optoelectronic devices attract the attention of scientists from diverse disciplines who explore new applications for optical disk drives and their components. Optical pickup heads have been used as separate detection units for scanning optical microscopy by Benschop and Rosmalen [3], for position sensing by Chu and Lin [4], and for biodetection by Lange et al. [5]. Applications of modified computer optical disk drives with additional photodetectors for transmission measurements were pioneered by Gordon [6] and were recently used for bioassays [7,8].

The use of computer optical disk drives for chemical and biological sensing has attracted our attention because of the potential to implement the drives without mechanical and optical modifications. During initial feasibility studies with manually deposited films, it was shown that the Lab-on-Disk system produced similar quantitative performance compared to a conventional spectrometer [9]. Next, a laboratory-scale automated production of sensing films with 14 different colorimetric chemistries per disk was developed [10]. A jewel-case fluidic system has also been developed that delivered controlled water volumes to multiple sensing films on the disk within a defined time window, enabling controlled reaction time of sensing films with water, and removed water prior to quantification in an optical disk drive [10]. A theoretical model of the system operation has been developed that took into account practical aspects of sensing films such as reagent leaching and film-thickness variability [10]. In addition, this system has been used for gas detection [11].

For chemical and biological sensing there are several attractive features for using unmodified optical disk drives with integrated compact disk optical pickup heads. These features include stray light rejection, wide acceptance of these readout systems, and cost-effective implementation. However, there were significant challenges in the implementation of this detection platform. These challenges include software drivers that are specific for each brand of CD–DVD drive, the need to extract the analog signal from the detector and to control the rotation speed of the disk, position of the laser pick-up head, laser auto-focusing, and setting the detector gain. These challenges were eliminated with our optical disk drive control approach [9].

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In this study, we demonstrate the multi-wavelength operation of the developed system for quantitative chemical analysis of chlorine in water samples. Super audio CDs that support operation of 650-nm and 780-nm lasers on the same optical disk were used. Combinatorial screening techniques [12,13] were applied to develop a formulated sensing chemistry for determining chlorine in water. Operating the optical disk drive at 650 and 780 nm provided an opportunity to correct for variability in film thickness when dual-chemistry sensing films were formulated and deposited onto SACDs. Response of sensing films was measured at the analytical wavelength (780 nm) and was normalized by the response at the reference wavelength of 650 nm, where the sensing film response was not affected by chlorine exposure. Such signal normalization corrected for the film thickness variability and improved the correlation coefficient R^2 in sensor response from 0.76 to 0.95. The resulting response curve was more linear with an improved precision of response. This performance enhancement was also seen in a twofold improvement of the limit of detection from 600 to 300 ppb through the use of dual-wavelength signal normalization.

2. Multi-wavelength operation

For chemical and biological detection using computer optical disk drives, an analog signal is captured from the drive's photodiode circuit and is mapped to optical changes in sensor films deposited on the read surface of CD or DVD disks. Conventional optical laser pick up heads operate at 650 nm for reading DVDs and at 780 nm for reading CDs. The emission at 650 and 780 nm is produced by a dual-wavelength integrated laser diode [14–17].

Blu-ray® disk technology has recently become a format of choice for high definition video. Blu-ray® optical disk drives add a 405-nm wavelength [18–20] that is attractive for expanding the range of optical sensing materials (e.g. freebase and metallo-porphyrins) for chemical and biological sensing. Optical laser pick up heads are now available that produce three wavelengths of 405, 650, and 780 nm [21].

Optical disks with multiple layers can be employed to activate more than one laser on the same optical disk allowing an array of sensing films to be read at multiple wavelengths. In this study, we utilized a SACD that has two reflective layers to operate with 650- and 780-nm lasers (Fig. 1). A typical SACD consists of a high-density (HD) 0.6 mm thick layer bonded to a 0.6-mm thick CD layer. The distance between the HD and the CD layer is large enough not to cause the layer-to-layer cross talk. The HD layer is reflective for the 650-nm light but is transparent at 780 nm (Fig. 1A and B). Thus, an independent reading of both layers is performed.

During the reading of an optical disk, the laser light is incident on the polycarbonate surface of the disk with an incident spot of several hundred micrometers, but is focused down ~1 μm into the polycarbonate substrate onto the interface between the molded polycarbonate pits and the metal reflective layer. This tight focusing, in addition to reading a dense array of stamped pits, minimizes the effects of dust and scratches on the disk surface, but still allows us to measure the response of a chemically sensitive film placed on the upper polycarbonate surface. For analytical measurements, the detector signal $I(\lambda)$ at different wavelengths λ_i is sampled at a frequency <10 MHz [9], which is below the data-sampling threshold that resolves individual pits on the optical disk. Thus, this detector signal is proportional to the change in the optical response $S(\lambda_i)$ of the sensing film deposited onto the read surface of the optical disk at different laser wavelengths λ_i:

$$S(\lambda_i) = |I_0(\lambda_i - I_E(\lambda_i)| \quad (1)$$

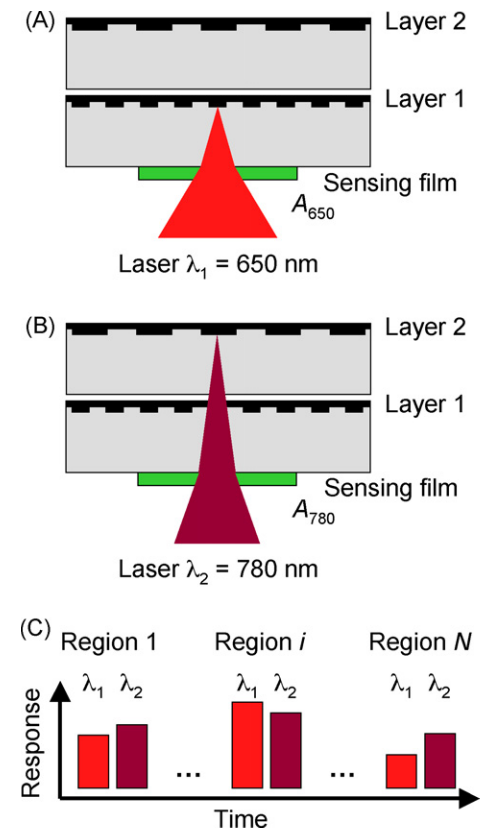

Fig. 1. Multi-wavelength operation of computer optical disk drives for chemical and biological analysis. (A) Excitation of the sensing film on SACD at 650 nm. (B) Excitation of the sensing film on SACD at 780 nm. (C) Sequential operation of two lasers on a same sensing film deposited onto the optical disk. In A and B, the reflective HD layer (layer 1) is reflective for the 650-nm light but is transparent at 780 nm. The reflective CD layer (layer 2) is reflective for the 780-nm light.

where I_0 and I_E are detector signals in presence of the sensing film that were unexposed and exposed to analyte-containing solutions, respectively. The optical response S of the sensing film is represented as an absolute value of the change $I_0 - I_E$.

Operation of optical disk drives at multiple wavelengths to read the array of sensing films is illustrated in Fig. 1C. New opportunities for the use of multi-wavelength optical disk drives for chemical and biological sensing are summarized in Table 1, and include expanding the diversity of sensing chemistries and the advantages of multivariate spectral processing.

Table 1
New opportunities for the use of multiple wavelength optical disk drives for chemical and biological sensing.

New opportunities	Examples
Expanding diversity of sensing chemistries	Sensing chemistries active at 405 nm Sensing chemistries active at 650 nm Sensing chemistries active at 780 nm
Multivariate spectral processing	Compensation for film thickness variation Compensation for film haze and surface texture Multivariate response analysis for selectivity improvement Multivariate response analysis for detection limit improvement