Multilayer films for optical data storage

Cory Christenson, Brent Valle, Jie Shan, and Kenneth Singer

A new multilayer polymer medium made using a continuous roll-to-roll process shows promise for the next generation of terabyte-scale optical data storage.

The amount of digital information being generated has accelerated greatly over the past few decades. The proliferation of high-definition media, mobile devices, and improved image techniques has increased both the number and the size of files created. Some of this data requires only temporary storage, but the ever-expanding digital footprint of companies and individuals calls for long-term storage options.

There are several technologies available to meet such demands. Flash memory is attractive for its fast data rate and portability, but it has limited read/write cycles and capacity. Spinning disk hard drives have become the most popular data storage medium due to increases in drive capacity and significant reductions in the cost per bit, but their lifetimes are insufficient for archival storage. Magnetic tapes can reach similarly high capacities and last for decades, but they have slow access times and require a relatively large initial investment in read/write hardware.

Optical data storage (ODS) provides an inexpensive, portable alternative with fast access times and long lifetimes. The trade-off for these advantages is in the comparatively low capacity of the format. Current state-of-the-art Blu-ray discs (BDs) can achieve up to 100GB/disc which, while sufficient for media, is not adequate for the large-scale archival data storage required by many companies and digitally-entrenched computer users.

The capacity of ODS is limited by optics and disc material. Capacity increases from CD to DVD and, finally, BD were achieved using shorter wavelength lasers and higher numerical aperture (NA) optics. Writing in BDs is already performed with a 0.85NA lens at a near-UV wavelength, which limits further increases to the in-plane storage density. Furthermore, the axial storage density is limited by multiple reflections and large scattering of the inorganic phase-change materials employed in these discs, which permit only a few data layers within the disc volume.

Current research into next-generation ODS technology has primarily focused on holographic data storage that could produce a disc with terabyte (TB) scale capacity. In the holographic approach, data is stored by interfering two laser beams in a medium: a uniform beam, and a beam with encoded information. The interference recorded in the medium can then be read by illumination with the uniform laser beam. The stringent requirements on both medium and read/write hardware have restricted the development of a commercially viable solution. Other approaches, including multi-layer Blu-ray discs (BDXL), have a smaller increase in capacity compared with current ODS technologies, and they have not yet been widely adopted.

We demonstrated the use of co-extruded multi-layer polymer films for ODS, which enables the fabrication of media with many closely spaced layers and greatly increases the axial density (see Figure 1). The thermoplastic polymers allow these films to be made in roll-to-roll fashion, significantly reducing the cost of the final product (see Figure 2).

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The medium consists of multiple thin, dye-doped, active polymer layers approximately 300nm thick, separated by optically transparent buffer layers with a thickness of 3μm. The active layers comprise 1% of the responsive dye 1,4-bis(α-cyano-4-octadecyloxystyryl)-2,5-dimethoxybenzene (C18-RG) doped in poly(ethylene terephthalate glycol) (PETG), and the buffer layers are fluorinated polymer poly(vinylidene fluoride). These layers reduce the background signal during reading and confine bits axially to a region much smaller than the Rayleigh range of the writing beam.

Writing was performed by permanent photobleaching with a 405nm continuous wave laser (as is used for BDs) near the absorption peak of the dye. The spot size of the bleached region is close to the diffraction limit of the laser and objective, and, thus, the areal density is similar to commercial optical discs.

We wrote a total of 23 active data layers in this manner: see Figure 2(b). Custom images were created using a laser scanning confocal microscope, but bitwise information has also been written. While many more layers can be produced by co-extrusion, these 23 layers occupy a region approximately 80μm thick. In comparison, commercial discs of the same depth achieve a maximum of four layers.

The films can be cut and laminated onto hard plastic substrates for integration into standard BD read/write optical systems. In this format, the storage density is sufficient for TB-level storage. Other formats, such as different sized discs, are also possible.

There is no observable cross-talk between successive layers, as can be seen in the images: see Figure 2(b). We quantified this by writing bits spaced by 1μm and found that the exposure in adjacent layers during the writing of 10 layers resulted only in a decrease in the overall background fluorescence level. The modulation signal is unaffected, up to the point where significant bleaching occurs over the entire sample. There are low levels of exposure as layers are written and read (due to the photoresponsive nature of the material and the spacing of the data layers), and these small exposures accumulate, eventually limiting the ability to distinguish between written and unwritten regions. However, this limitation can be overcome by using optimal spacing for the data layer, and a nonlinear or threshold photoresponse of the storage medium.

In summary, we developed a method of optical data storage using co-extruded multi-layer polymer films. This technique greatly increases the axial density compared to current commercial discs and can be manufactured relatively inexpensively using a roll-to-roll process. Our future work aims to optimize thermally stable materials by improving both the response and the bit density. These new materials have the potential to create a storage medium with large density, low cost, and long lifetime.

Author Information

Cory Christenson, Brent Valle, Jie Shan, and Kenneth Singer

Department of Physics
Case Western Reserve University
Cleveland, United States

Cory Christenson is a postdoctoral scholar. He received his PhD in optical sciences at the University of Arizona.

Brent Valle is a graduate student.

Jie Shan is an associate professor. She received her PhD in physics at Columbia University.

Kenneth Singer is the Ambrose Swasey professor of physics. He received his PhD in physics from the University of Pennsylvania.

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References