Optera Data: High-Density Optical Data Storage - Using multilevel persistent spectral hole-burning

1). Introduction:

Optical data storage is believed by many to hold the key to increasing digital data storage capacities largely due to its potential for multilevel data encoding in which multiple bits can be stored per point. In recent times a range of advanced optical data storage techniques have been reported in the literature [1-3]. Such techniques have however often been plagued by the requirement of high-power (e.g. femtosecond) pulsed lasers for writing which severely limits real-world applications. Many of the methods reported to date have also required cryogenic temperatures [4], or complex read-out processes including holographic or super-resolution readout [2,3].

Optera Data's data storage technology relies on a novel approach to optical data storage involving room temperature persistent spectral hole-burning that overcomes many of the impracticalities of previously reported techniques and methods. We note that multilevel optical data storage has previously been demonstrated in photochromic polymers and organic dyes without spectral hole burning. Such materials were however highly limited in their data storage potential (i.e. due to low dynamic range and low linearity of the signal) as well as there being question marks over the long-term data storage prospects due to bleaching and destructive read-out. Such systems have therefore typically been limited to only several bits/point encoding [5,6]. Optera Data's approach is a novel technique that uses nanocrystalline/particle systems in conjunction with room-temperature persistent spectral hole-burning to store multiple bits/point without use of high-power pulsed lasers or requiring cryogenic temperatures.

Persistent spectral hole-burning within a nanocrystalline system involves a laser frequency being in resonance with the transition of a subset of optical centres within an inhomogeneous distribution (Note: an inhomogeneous distribution occurs due to imperfections in the crystal lattice, isotope distributions etc — leading to an overall, typically normal distribution of electronic transitions). The excited subset can then be subject to some photochemistry and this leads to persistent spectral hole-burning i.e. a narrow dip is observed at the initial laser frequency when the laser is scanned across the profile. The basic idea has been to use the spectral holes to encode binary 0s or 1s. The number of holes that can be burnt into an inhomogeneous transition is given by the ratio of the inhomogeneous to homogeneous linewidth which is the key figure-of-merit. This ratio can be up to 10^8 at very low temperature and hence incredible data storage densities are possible albeit at impractical liquid helium temperatures. However, in most cases the homogeneous linewidth is dominant at room temperature i.e. room temperature spectral hole-burning has been reported for very few systems only. This is because of the rapid dynamic broadening of electronic transitions that occurs due to interactions with phonons, resulting in large homogeneous linewidths that are typically larger than the inhomogeneous broadening at room temperature, preventing narrow dips from being burnt into the spectrum [7,8].

For hole-burning technologies to be viable for data storage applications and to ensure energy efficiency, the importance of being able to store the information at room temperature rather than requiring very low cryogenic operational temperatures is key and forms part of the novelty of Optera Data's approach. The best hole-burning systems, so far, all revolve around divalent samarium such as $BaFCl:Sm^{2+}$. For example, it is possible to burn several holes (i.e. several bits) at room temperature into $Ba_{0.5}Sr_{0.5}FX:Sm^{2+}$ systems [8].

Optera Data uses a novel approach to allow for a dramatic increase in the number of holes (or bits) that can be burnt at room temperature [7-9].

2). Technology Overview:

Chemically-different nanocrystalline particles are used in a mixture to broaden the effective inhomogeneous linewidth as seen by a laser source focused to a spot given by the diffraction limit. The individual nanocrystals/particles have slightly different central emission wavelengths by virtue of their composition – as shown in Fig. 1. When viewed with a laser spot size larger than the individual nanocrystals an effective broadening of the inhomogeneous linewidth of the system is seen.

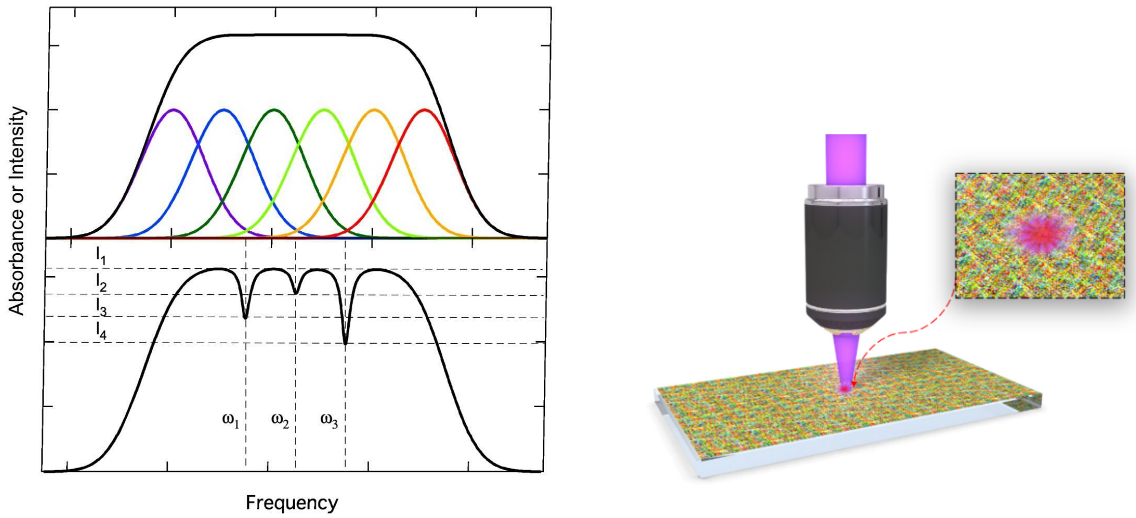

Figure 1: Optera Data's storage mechanism in which the superposition of at least three Gaussian luminescence or absorption peaks of roughly the same width and spacing create a flat-top distribution. (b). The flat-top or similarly-broadened distribution is ideally suited to spectral hole-burning which is a form of frequency domain optical data storage, in which the individual hole depths could in addition be discretised to encode multiple bits per spectral hole [9].

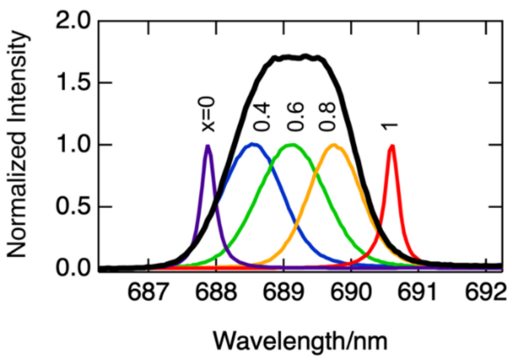

Figure 2: Room temperature luminescence spectra in the region of the Sm^{2+} $^5D_0 \rightarrow {}^7F_0$ luminescence line in $Ba_{1-x}Sr_xFCl$ for x=0, 0.4,0,6,0.8 and 1. The black trace shows the corresponding luminescence spectrum for an optimised physical mixture of the nanocrystals, yielding a flat top that is better than 1% [9].

3). Technology Projections:

The first generation of the technology would see a 500 GB proof of concept using multi-wavelength and multilevel room-temperature persistent spectral hole burning. With further refinements, the data storage capacity could be pushed to the 1 TB level.

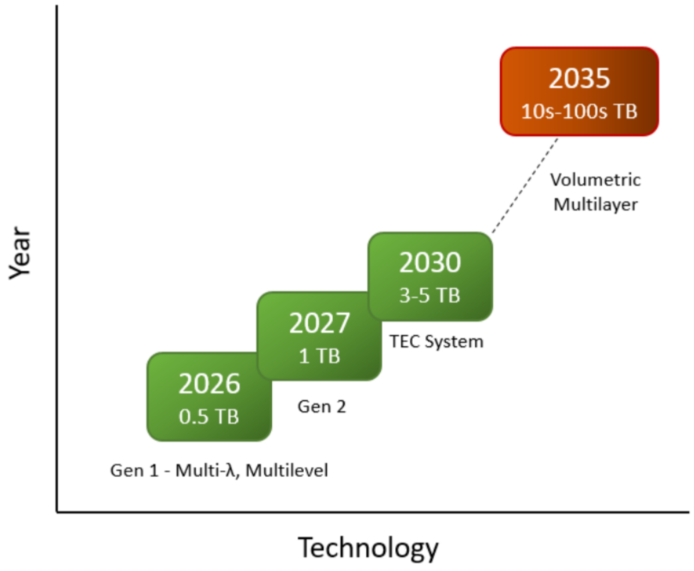

Figure 3: Optera Data technology predictions and roadmap.

With thermoelectric cooling this capacity can be pushed further to up to 5 TB. Beyond this, 3D volumetric or multilayer techniques can be used with the nanocrystalline material incorporated into a 3D host to permit up to 100s TB in future generations of the technology.

4). References:

1. Zijlstra, P., J.W. Chon, and M. Gu, Five-dimensional optical recording mediated by surface plasmons in gold nanorods. Nature, 2009. 459(7245): p. 410-413.

2. Gu, M., X. Li, and Y. Cao, Optical storage arrays: a perspective for future big data storage. Light: Science & Applications, 2014. 3(5): p. e177.

3. Gu, M. and X. Li, The road to multi-dimensional bit-by-bit optical data storage. Optics and Photonics News, 2010. 21(7): p. 28-33.

4. Schellenberg, F.M., W. Lenth, and G.C. Bjorklund, Technological aspects of frequency domain data storage using persistent spectral hole burning. Applied optics, 1986. 25(18): p. 3207-3216.

5. Gu, M., et al., Effect of saturable response to two-photon absorption on the readout signal level of three-dimensional bit optical data storage in a photochromic polymer. Applied Physics Letters, 2001. 79(2): p. 148-150.

6. Savoini, M., et al., All-optical subdiffraction multilevel data encoding onto azo-polymeric thin films. Optics letters, 2009. 34(6): p. 761-763.

7. Riesen, H., et al., Highly efficient valence state switching of samarium in BaFCl: Sm nanocrystals in the deep UV for multilevel optical data storage. Optical Materials Express, 2016. 6(10): p. 3097-3108.

8. Wang, X., et al., Room temperature hole-burning of X-ray induced Sm2+ in nanocrystalline Ba0. 5Sr0. 5FCl0. 5Br0. 5: Sm3+ prepared by mechanochemistry. The Journal of Physical Chemistry A, 2014. 118(40): p. 9445-9450.

9. Riesen, N., et al., Data storage in a nanocrystalline mixture using room temperature frequency-selective and multilevel spectral hole-burning. ACS Photonics, 2021. 8(10), 3078-3084.