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High Density Optical Memories for Safe Archival Data

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Author's contribution

This whole work was carried out by the author SK.

Short Research Article

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ABSTRACT

Ion nanobeams are used to write data bits of nanometer diameter into storage materials and photon near-field technology is employed to read this novel kind of digital memory.

Keywords: Nanotechnology; tbit memory capacity.

1. INTRODUCTION

Present-day digital memories are subject to lifetime limitations of the order of some 10 years due to physico-chemical deterioration effects at ambient temperatures. Thus, for cultural values of all kinds to be preserved for future generations, other ways have to be found providing unlimited lifetimes. Also, the steadily increasing amount of digital data of global order of zetta bytes will require novel storage techniques of ultra-high density [1].

1.1 Experimental Background

A very important application of Xe nanobeams pertains to the fabrication of permanent (non-volatile) optical data memories (WORM type) of Tbit capacity. A first outline of this idea was presented about 10 years ago, without, however, specifying a reading process [2]. This latter task is addressed in the following. Bit creation makes use of local phase transitions of initially monocrystalline silicon layers (c-Si) to the amorphous state (a-Si) locally changing optical absorption for incident photons of energies $hv \leq 3.0$ eV Irradiation with ion nanobeams with

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fluences of about 10^{13} Xe ions/cm^2 of 15 keV energy will amorphise irradiated Si-areas of about 10 nm diameter to a depth of 20 nm, comprising a bit volume of about $2{\cdot}10^{-18}$cm^3 constituing to a solid state equivalent of 10^5 Si atoms.[2,3]. Fig. 1 displays calculated ion trajectories of a total of 10^5 ions of a 15keV Xe sub-nm beam in c-Si.[7] Evidently, the implantation profile will vary with beam energy and size, so that both smaller and larger bit sizes can be produced. Due to the vertical bit arrangement, a storage density *n* of bits *b* of diameter *D* = 2*R* amounts to

$$n{\sim}10^2\,(D[\mathrm{nm}])^{-2}\;\;Tb/\mathrm{cm}^2\,. \tag{1}$$

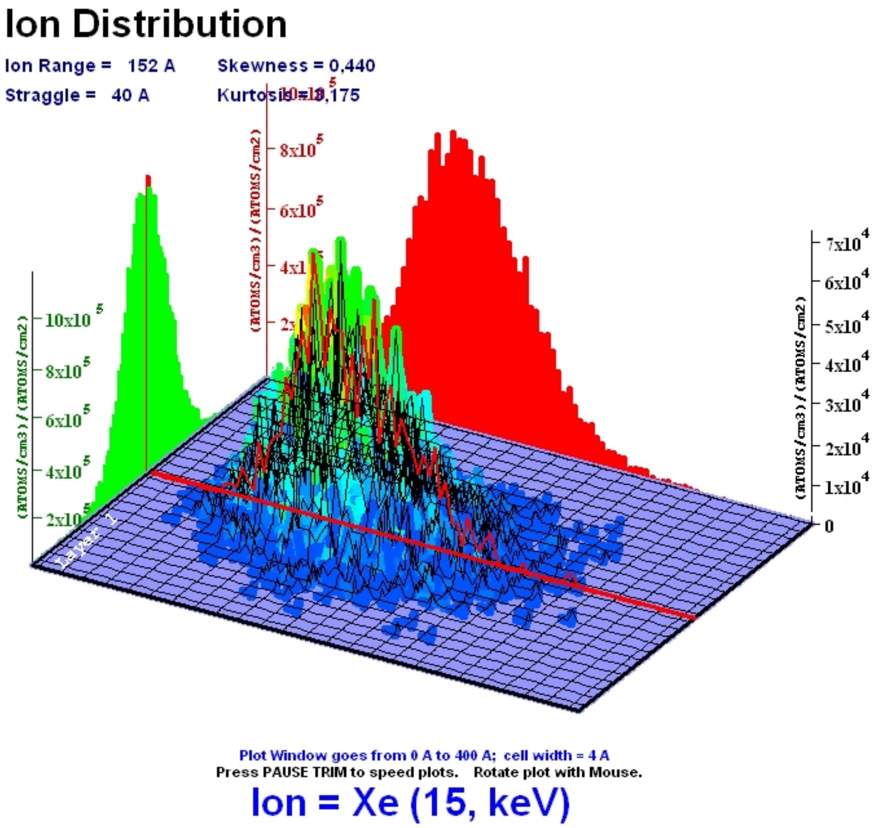

Fig. 1. Implantation profile of a pencil beam of 10^5 Xe ions of 15 keV into c-Si with the main range parameters shown: Ion longitudinal range: L_l~20 nm, lateral radial diameter: L_r~10 nm. (Color on line). Calculation with the computer code SRIM. [7].

Thus, for *D* = 10 (100) nm, a standard disk of 100 cm^2 area would provide space for100 (1) Tbit of data, distinctly beyond any presently available capacity of standard storage media. Recently reported maximum densities are about n~0.4Tb/cm^2 [4]. Suitable storage material is silicon-on-sapphire. It is available as single-crystalline hetero-epitaxial c-Si layers of about 100- 1000 nm thickness grown on transparent monocrystalline Al_2O_3 substrates (commercially available as silicon-on-sapphire or 'SOS' from Kyocera, Japan). But also other wider-gap insulators such as c-SiC and pc-diamond may be considered [2]. c-Si has absorption coefficients of $\alpha_c \sim 10^4$cm^{-1} at *hv*~3.5 eV and a-Si up to $\acute{\alpha}_a \sim 10^6$ cm^{-1}, providing sufficient contrast by differing transmissions T_c and T_a of an incident light beam [2]. Detailed annealing studies have shown that these amorphised Si-regions do not recrystallise below temperatures of about 600°C; [1,2], so that the stored information is of practically unlimited lifetime at ambient temperatures in all global climates, in contrast with all presently available storage technologies. Also, its immunity against even strong electromagnetic transient fields is an important feature for many civil and military environments. The topic of light transmission through sub-wavelength apertures has a long history comprising both 'scalar' and 'vectorial' teatments with Bethe's predicting the total transmitted light power P_t of the incident photon flux density [4]. Details in section III. The very major technical challenge is the optical reading of such memories. Near-field technology based upon light transmission through small apertures, as described by Bethe [5] and experimentally checked by Robertson [5], subsequently transmitted or absorbed by crystalline or opaque zones, respectively, appears a viable approach. More details in section 1.2. The procedure is illustrated by Fig. 2. Incident laser light of intensity I_0 and wave length λ ~ 500 nm, or energy $h\nu$~2.5eV, p Further enhancements are possible by optimising silicon layer thickness, ion implantation parameters, and photon energy, improving the optical effects. Even at moderate laser intensities a memory density of at least 10^{10} b/cm^2 appears readable as shown below.

1.2 Theoretical

The topic of light transmission through subwavelength apertures has a long history, starting with the initial 'scalar' theoretical approach by Kirchhoff, followed by several 'vectorial' treatmemts with Bethe's [4] predicting the total transmitted light power P_t of the incident photon flux density I_0 through an aperture radius R:

$$P_t = c\,(kR)^4(R^2 I_0) \tag{2}$$

Experiments with I_0 of 1 *mW* laser radition incident onto 1mm^2 area in the focal plane of a screen confirmed the R^6-dependence of the transmitted power (eq.2) over a wide interval of aperture radii R.[5] c is a constant of order of unity for normal incidence of light and the wave vector is $k = 2\pi/\lambda$ = 0.00126 nm^{-1} for λ = 500 nm provides digital information with contrast κ = (Tc-Ta)/Ta ~ 1 to be recorded by an ultrafast photo diode Let I_0 be the laser light intensity within a monomode fibre with a kernel radius R_k= 2.5 μm (Fig. 2).We assume $I_0 = 10\ mW/\pi R_k^2 \sim 5{\cdot}10^8$W/m^2, equivalent to an areal photon flux density of $I_0 \sim 1.3{\cdot}10^{27}$ hν/m$^2{\cdot}$s. Thze screen is usually coated onto the front end of the fibre. For simplicity we assume a homogeneous intensity across the kernel cross section. Out of the total power P_T transmitted through the aperture a fraction $P_{c(a)}$ per scanned bit

$$P_{c(a)} \sim q.\cdot T_{c(a)} \cdot c \cdot k^4 \cdot R^6 \cdot I_0. \tag{3}$$

wil reach the photo diode in case of a c(a)–bit-area. The reduction factor q depends on the exact geometry of the optical arrangement. q ~ 10% may serve as a rough estimate of the solid angle subtended by the bit area in Fig. 2, where equal diameters D of aperture and bit-area have been presumed. Multiplication with the bit scan time τ yields the detectable number of photons per x scanned bit

$$N_{c(a)} = P_{c(a)} \cdot \tau.$$

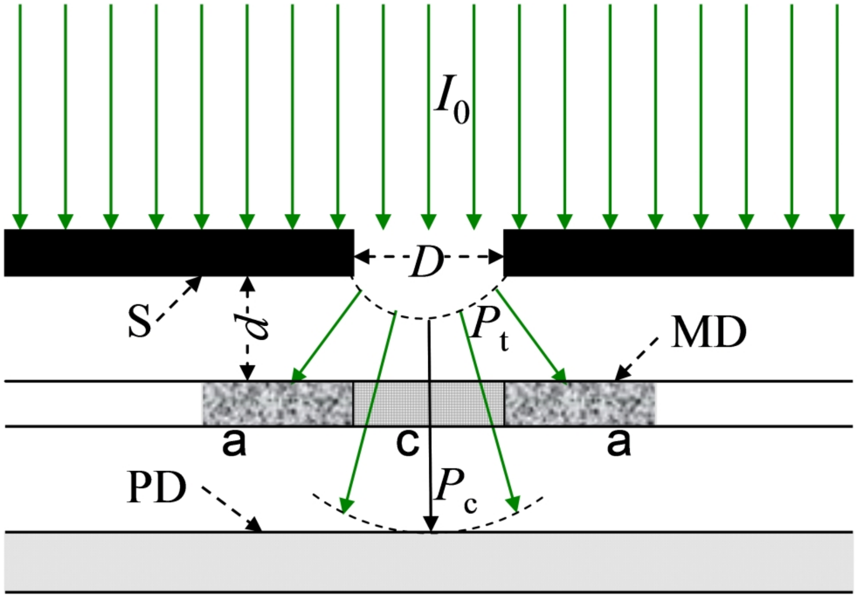

Fig. 2. Scheme of the optical reading arrangement: A 5 µm wide kernel of a monomode fibre carries laser light of wavelength $\lambda \sim 500$ nm (2.5 eV) and intensity $I_0 = 10$ mW/(ΣΠχξπ2.5 µm)^2) (equivalent to $1.3 \cdot 10^9$ photons/(nm^{2}s)). The light strikes a $D = 20$ (200) nm wide aperture of an opaque screen (S). The transmitted power P_t of $3.3 \cdot 10^{7(13)}$ *hv*/s hits the rotating memory disk (MD) consisting of transparent, crystalline (c) or opaque, amorphous (a) silicon bit areas. The light power $P_{c(a)}$, passing bit areas c(a) generate bit signals $N_{c(a)}$ in the fast photo diode (PD). (Color on line)e (PD). (Color on line)

In further specifying the reading process we consider $q = 0.1$, $T_c = 1$ and a lower (upper) bound of aperture radius $R = 10(100)$ nm, and $I_0 = 1.3,\ 10^{27} hv$ /m^{2}s. The corresponding transmission cross section of the aperture is $k^4 R^6 = 2.5 \cdot 10^{2(+4)}$ nm^2 according (3). The power received at the photo diode by passing a c-bit is then $P_c = 3.3 \cdot 10^{6(12)}\ h\ v$ /s according (3). With scan frequencies of $f = 1/\tau = 10^{7\{9\}}$ Hz the number of detectable photons per scanned c bit will be $N_c = 3.3 \cdot 10^{-1(+5)\{-3(+3)\}}$ photons. N_c presents the digit 1. As said above, the corresponding figure for the digit 0, representing the photon beam passing an amorphous zone is much smaller and constitutes a threshold level of $N_a << N_c$ so that a sufficient signal contrast is achieved in the response of the fast photo diode.

In Fig. 3 the results for N_c are plotted within the considered ranges of the bit size. For $R > 20$ nm and a dwell time of 10^{-7} s/bit we have signals $N_c > 10$ photons, likely sufficient for safely reading the bits in view of the quantum efficiency of present photodiodes exceeding 50 %. The smallest, about 10 nm wide bit areas achieved by ion implantation in ref. [2], however, can be read only at kHz rates with the light intensity considered here – quite unpractical for a multi-Tbit memory. Ultrafast photodiodes have rise times ~2ns and hence can handle well above 10^8 signals per second. Exploiting this limit would require a bit radius $R \sim 20$ nm.

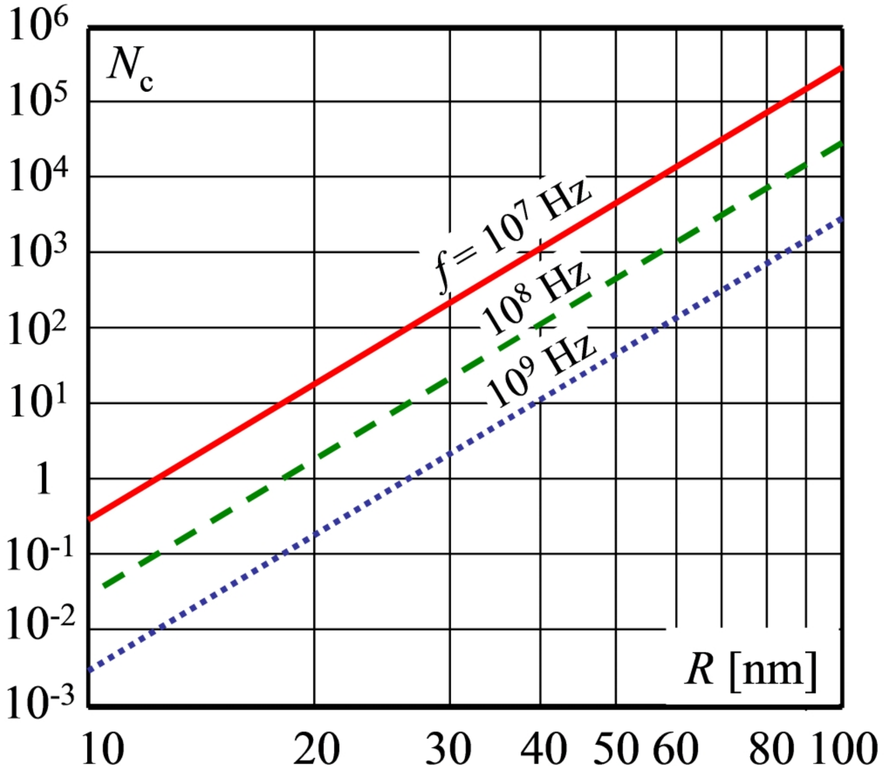

Fig. 3. Number of photons N_c passing a c-bit area and hitting the photo diode for beam dwell times of τ = 100, 10, and 1 ns/bit as function of aperture radius *R*. (Color on line)

In conclusion, the proposed optical memory has unlimited lifetime and will work with an upper capacity limit of about 6 *Tb/*disk, readable at a bit rate of 100 *MHz*. By optimisation of the numerous parameters even higher values seem accessible.

Richard Feynman's intriguing question: Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?, based on a pixel size of 8 nm, can now be answered with: Yes, we can!

2. DISCUSSION

Although this investigation has shown the feasibility of achieving the initially stated goals for permanent safe archival dense data storage, we have to stress that the whole process requires high-technology processing steps, e.g. the use of xenon nano-beams of nA intensity. Such equipment is not yet commercially available. Depending on the importance of the respective data, costs nevertheless look affordable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Available: www. emc.com/digital universe
2. Kalbitzer S. Novel concepts for the mass storage of archival data. Nucl. Instr. and Methods B218. 2004:343-354.
3. Kalbitzer S, Zhukov VA. The Development of Ion Nano-beams- A Review. Appl. Phys. Res. 2012;4:211-221, and V.A. Zhukov and S. Kalbitzer: Advantages of the Use of Supertip Xe+ Sources with Field Gas Ionization in Ion Microscopes, Russian Microelectronics, 2011,Vol. 40; No.1, pp.17-24, Pleiades Publishing, Ltd.; 2011.
4. Times EE. 08/18/2010 quoting Toshiba results.
5. Bethe HA. Theory of Diffraction by Small Holes. Phys. Rev. 1944;66:163-182.
6. Roberts A. Coupling of radiation into a near-field probe. J. Appl. Phys. 1991;70(8):4045-4049.
7. SRIM by J: F: Ziegler. J: P: Biersack and M: D: Ziegler. University of California at Los Angeles. CA 90066; 2012 (Available: www.SRIM:org.)

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