Enhancement of three dimensional optical data storage density through photo bleaching

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CD and DVD technology

- The data storage density of these media is equal to 1/λ2 (With green light of roughly 0.5 μm wavelength this should lead to 4 bits/ square micron or more than 4 Gigabytes (GB) on each side of a 120mm diameter, 1mm thick disk)
- The implementation of blue-violet laser diodes in optical disk systems will lead to an increase of the storage capacity by the factor of 2.5.
- Further increase may be achieved by using a dual-layer configuration.
- These surface based technologies are reaching fundamental physical limits that may be difficult to overcome.

dramatically increase data storage density

- Add one more axial dimension to the recording process.
- The data are thus written not on the material surface but within its three-dimensional volume.
- The data that can be stored in the above mentioned disk are then approximately 1/λ3 leading to a 2000-fold increase in data storage density reaching capacities of 8Terabytes
- It is based on two-photon absorption (TPA).

A new method for improving 3-d data storage density

- Increase the quality of service in telecommunication systems
- Based on three-photon induced photo bleaching of a polymer film doped with a fluorophore molecule
- It is a combination of TPA and excited state absorption.
- The recording process is photo bleaching, which is in total a three photon process for memory material.
- The term photo bleaching includes the photochemical reactions that permanent remove a molecule from absorption-emission cycle.
- The efficiency and the three-photon, step-wise, nature of photo bleaching of this optical material increase resolution of recording in an easy manner

Experimental-Methods

- The storage medium is a polymer film of PMMA doped with a pyrylium salt.
- PMMA has good optical and thermal behavior and is transparent at the wavelength of TP excitation.
- The pyrylium salt has a large TPA cross-section and high quantum yield.
- These parameters are crucial for TP recording so that the incident light will be used efficiently to write and read information.

Experimental-Methods

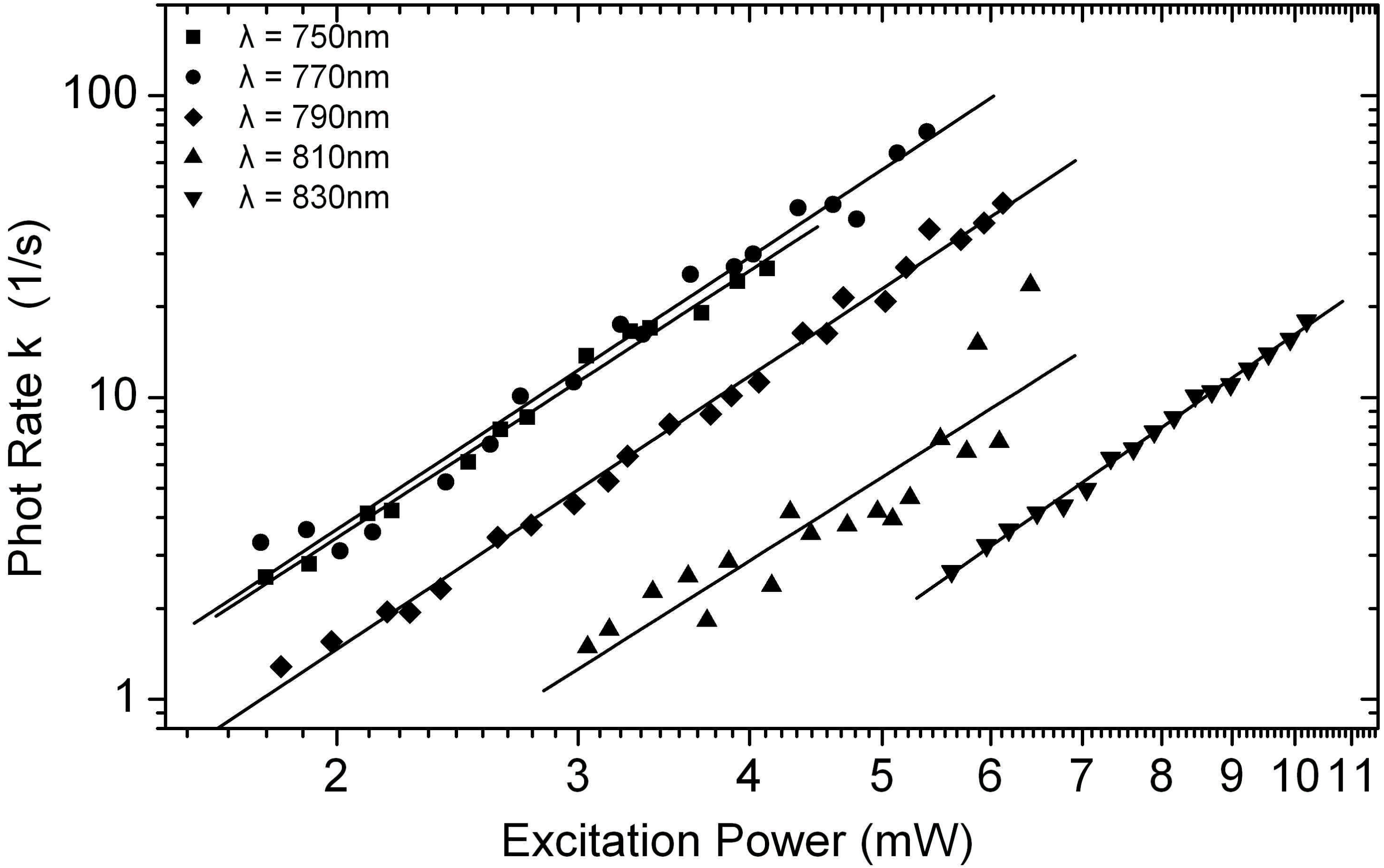
- A near infrared pulsed laser is used to excite the fluorophore molecule that normally absorb in the UV region (most fluorophores absorb in the UV or deep UV region).
- At such a wavelength many limitations of UV lasers and UV optics are avoided.
- The beam is tightly focused with an objective lens of high magnification to provide the high intensities needed for multiphoton excitation.
- By scanning the focal volume in all dimensions, one can fabricate 3D patterns of fluorescent and non-fluorescent spots inside the memory material with pinpoint accuracy.
- The non-fluorescent spots are recorded through the photo bleaching process.

Results and discussion

- The proposed recording mechanism is based on photo bleaching.
- The main characteristic of this process, which determines the efficiency of recording, is the photo bleaching rate *k* of the fluorophore molecule.
- Figure 1 shows the photo bleaching rate of the pyrylium salt versus excitation power, in the wavelength range of our laser system.
- It is obvious that at 750 nm photo bleaching is more efficient than the other excitation wavelengths. In addition, the high values of *k* ensure a fast bleaching of the pyrylium salt.
- Furthermore, the photo bleaching rate depends on the third power of excitation power revealing the involvement of three photons in the process.

Fig. 1:

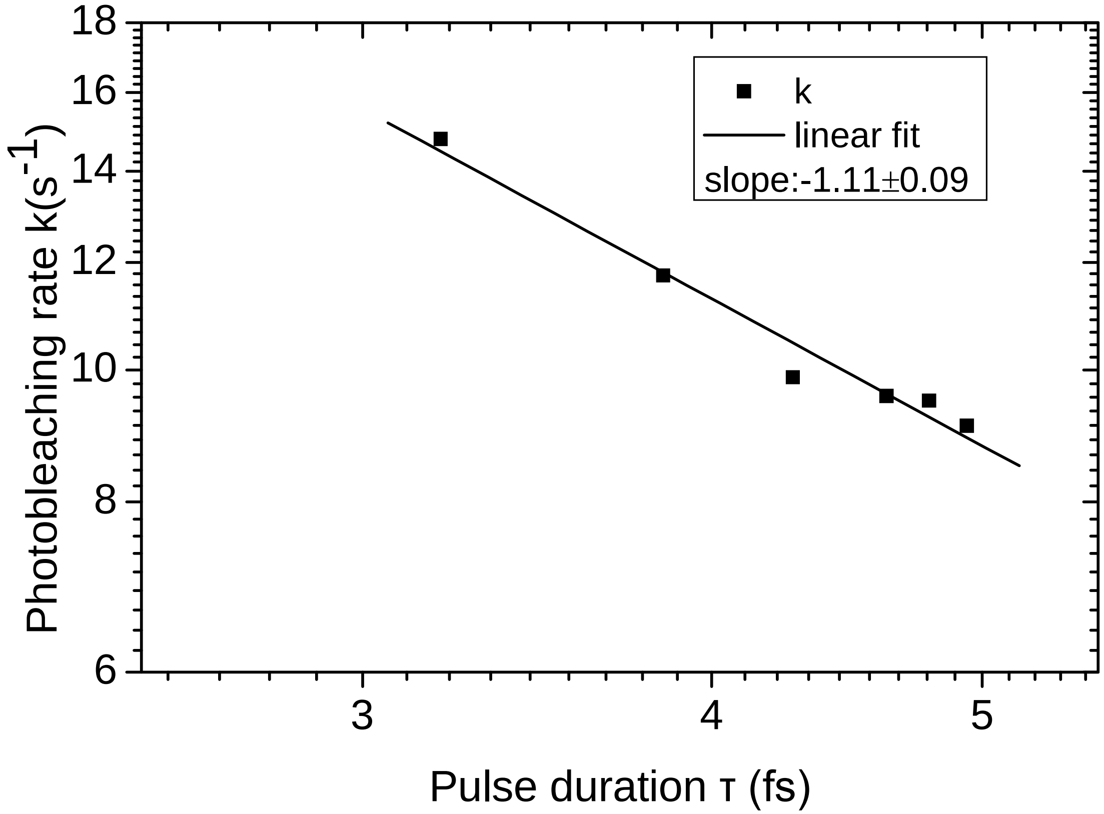
Photo bleaching rate *k* of the memory material versus excitation power (pulse duration ~100 fs, repetition rate 82MHz). Both axes are in logarithmic scale



Results and discussion

- Usually the simultaneous absorption of three photons demands large excitation power values.
- As it is shown in fig. 1 this does not happen in our memory material. Only a few mWs are needed to take place the photo bleaching process.
- This observation is very critical since the main disadvantage of three-photon absorption is eliminated.
- The explanation to this behavior is that photo bleaching occurs not with the simultaneous absorption of three photons but with the simultaneous absorption of two photons and the subsequent absorption of one photon from an excited state. This is experimentally verified with figure 2.
- The dependence of photo bleaching rate on pulse duration reveals the details of the photo bleaching process. In order to have the simultaneous absorption of three photons k should be analogous to $1/\tau 2$, where τ is the pulse duration. Unlike, *k* is analogous to $1/\tau$ showing that a stepwise absorption of three photons takes place.

Fig. 2:
Dependence of photo bleaching rate *k* on pulse duration (film concentration=1% wt, *λ*exc= 770 nm, excitation power *P*= 7.5 mW). Both axes are in logarithmic scale

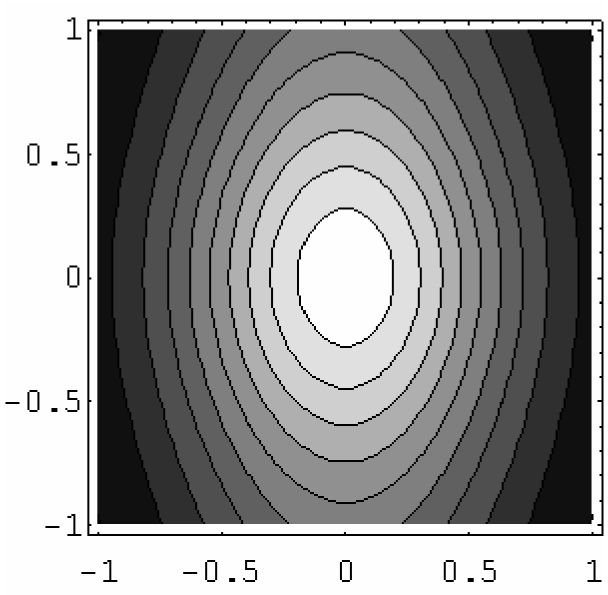


Results and discussion

- The fast bleaching offers a key for efficient recording at low power values.
- Furthermore, because of its dependence on the cube of the incident power, the efficiency of recording can be increased significantly with a small increase in irradiation power.
- Finally, the involvement of three photons in the process offers enhanced spatial resolution.
- Figure 3 shows the theoretically calculated spatial resolution of photo bleaching for one-, two-, three- and four-photon processes.
- It is apparent that as more photons involved in the photo bleaching process as better recording resolution is achieved.

Fig. 3:

Spatial dependence of the photo bleaching rate for multiphoton processes (horizontal axis -*r*/*w*0, vertical axis -*z*/*z*R). Photo bleaching is assumed to be analogous to ekt [reference] 1-photon 2-photon



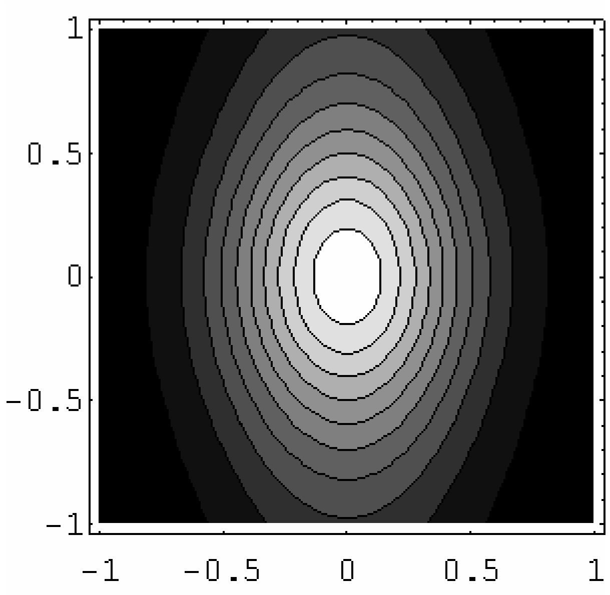
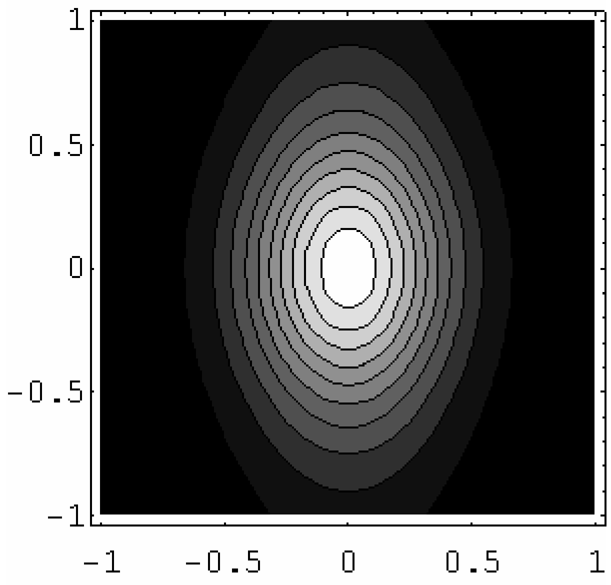


Fig. 3:

Spatial dependence of the photo bleaching rate for multiphoton processes (horizontal axis -*r*/*w*0, vertical axis -*z*/*z*R). Photo bleaching is assumed to be analogous to ekt [reference] 3-photon 4-photon



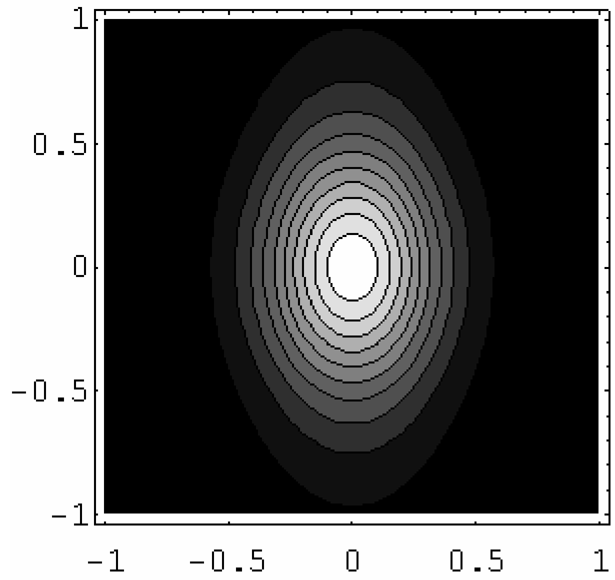


Table 1:
Comparison of the dimensions of the photo bleaching region for N-photon processes

N-photon process	R (FWHM) / W0 *w*0 beam radius	Z (FWHM) / ZR zR the Rayleigh length
1	1.17741	2
2	0.83255	1.28719
3	0.67978	1.01965
4	0.58871	0.86996

Results and discussion

- The fast photo bleaching mechanism, being a step-wise, three-photon process, provides a means for fast and sharp recording.
- The already small volume excited by simultaneous two-photon absorption is restricted more.
- In particular, the excited state absorption occurs inside this volume but its linear dependence on intensity results in sharper photo bleaching in the central area of the volume (where the light intensity is higher).
- This stepwise photo bleaching-recording mechanism avoids problems that could be appeared in simultaneous three-photon photo bleaching such as the need for large intensities, the beam homogeneity, the dissociation of the molecule etc.

Results and discussion

- The research on materials with photo bleaching behavior similar to the one described here may be a guide for improving 3-d data storage density.

- Indeed, the analysis presented here could be extended in other recording mechanisms like photo-chromism, photo-isomerization, photo-induced birefringence etc.

Conclusion

- A new method to increase three-dimensional data storage density is introduced.
- An advantage of this method is the low cost and easy fabrication of the materials.
- Furthermore, recording is implemented with the same experimental setup used for TP recording.
- The main drawback is located to the cost of commercially available ultra-short laser systems.
- However, the research on femtosecond lasers may drastically reduce cost in the forthcoming years