Plasmon enhanced three-dimensional multi-layer optical disk

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Outline

1. Background
   - Fluorescent recording/reading
   - Enhancement of read-out signal by combination of fluorescent dye with gold nano particle
2. Recording Material
   - Rhodamine-B and Au(III) doped PMMA medium
   - Basic properties
3. Plasmon enhancement of the signal from fluorescent recorded multi-layered optical disk

For high density recording (large capacity recording)

Decrease the size of light spot for small marks

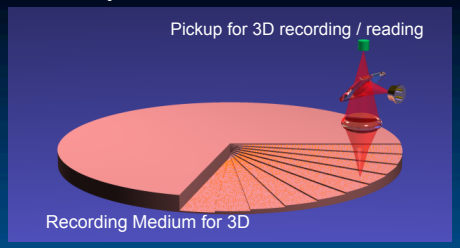
- Near field
- Solid Immersion
- Super-RENS
- Phase change
- Thermal assist
- ....

Enlarge the recording area (space)

- Hologram
- Multi-layer
- Three-dimensional
- FOD
- ....

Enlarge the recording area by piling up the recording layers

2D -> 3D (x-y-z)

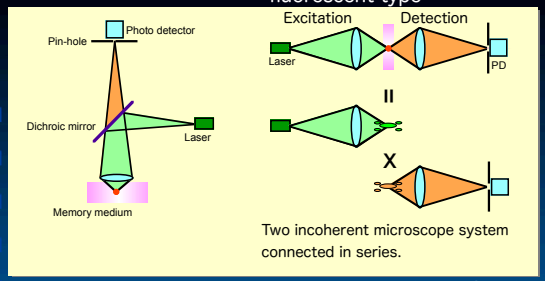


3D is big challenge for optical system

Conventional optical pickup
no 3D resolving power; lack of the resolution along z-direction

Confocal microscope

fluorescent type



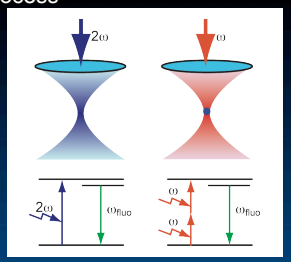
Point spread function of confocal system → the square of the PSF of incoherent system.

→ 3D resolving power

Optical pickup for 3D multi-layered memory

- Confocal microscope technique
  Nonlinear response comes from optical detecting system (point detector)
  → reading

Two-photon process



- 2 photons of long wavelength light are absorbed simultaneously.
- Probability ∝ the square of light intensity. (Non-linear effect)
- Only at the focusing spot -> light is absorbed.
  Other area -> transparent. <- light can penetrate deeply (no absorption, small scattering coefficient)

Optical pickup for 3D multi-layered memory

- Confocal microscope technique
  Nonlinear response comes from optical detecting system (point detector)
  → reading
- Two-photon microscope technique
  Nonlinear response comes from the light interaction with materials
  → recording / reading

Optical pickup for 3D multi-layered memory

- Confocal microscope technique
  Nonlinear response comes from optical detecting system
  → reading
- Two-photon microscope technique
  Nonlinear response comes from the light interaction with materials
  → reading / recording

↓

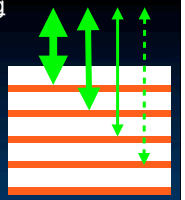
- Confocal fluorescent read-out with 3D spatial resolution
- Record data by two-photon process as a fluorescent pattern in 3D

Advantage/disadvantage of fluorescent recording

- O Signal light (fluorescent) comes only from the recording position
  - ·Low background
  - ·High S/N reatio cf. holographic memory
- O Signal light comes with different wavelength
  - •Easy separation from the irradiated laser light.
  - •Reflected excitation laser -> servo signal w/o interaction with signal light.
- X Bleaching of fluorescent dye
  - ·Optimization of read-out laser power.

Contradiction in 3D optical recording

3D memory (in particular Reflection type)



High intensity signal

↓

High reflectivity from recording layer

↓

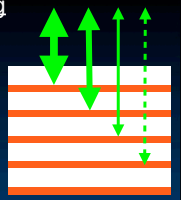
Light can not penetrate deep into the disk

↓

The number of recording layer is limited.

Contradiction in 3D optical recording

3D memory (in particular Reflection type)



High intensity signal

↓

High reflectivity from recording layer

↓

Light can not penetrate deep into the disk

↓

The number of recording layer is limited.

High intensity irradiation

↓

Necessary high power laser
Take care of destruction of medium

Retrieve data with low intensity light irradiation

Retrieve data with low intensity light irradiation

↓

Enhancement of the signal

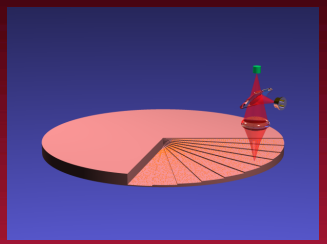
Advantage/disadvantage of fluorescent recording

- O Signal light (fluorescent) comes only from the recording position
  - ·Low background
  - ·High S/N reatio
- O Signal light comes with different wavelength
  - •Easy separation from the irradiated laser light.
  - •Reflected excitation laser -> servo signal w/o interaction with signal light.

+

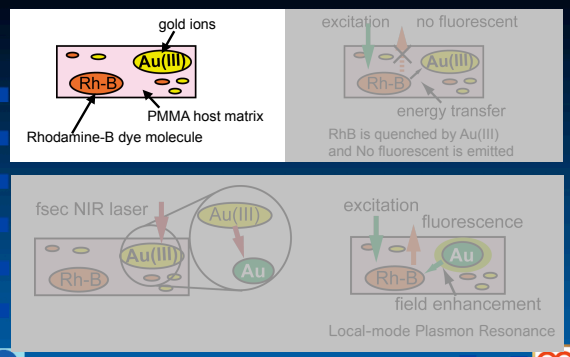
Introduce of some mechanism of the enhancement of the signal

Recording medium for 3D fluorescent recording with signal enhanced reading

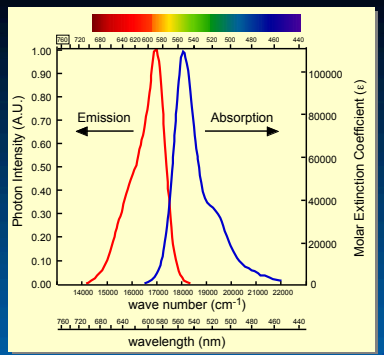


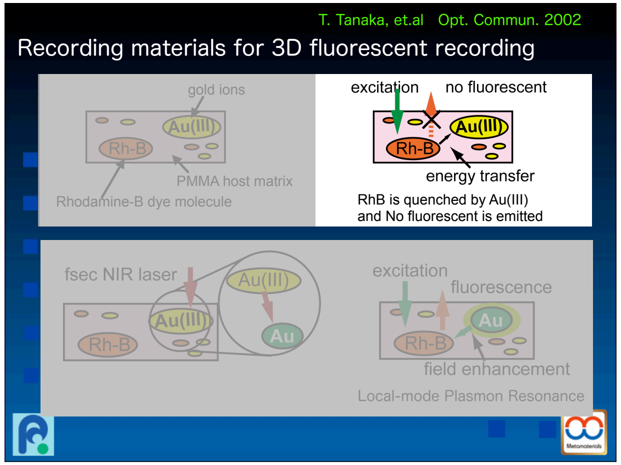
T. Tanaka, et.al Opt. Commun. 2002

Recording materials for 3D fluorescent recording



Rhodamine B

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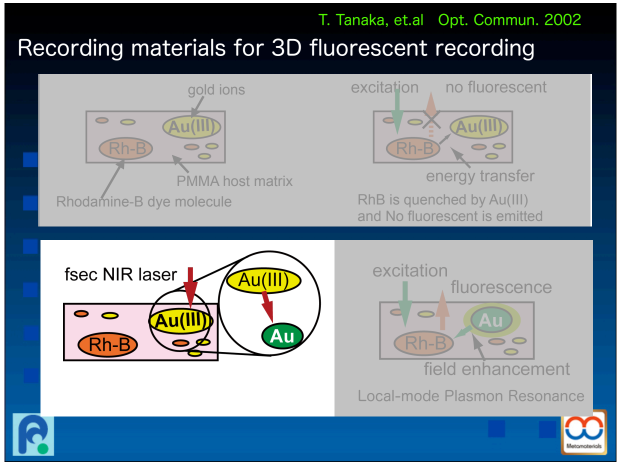
Recording materials for 3D fluorescent recording
gold ions
Au(III)
Rh-B
PMMA host matrix
Rhodamine-B dye molecule
excitation
no fluorescent
energy transfer
RhB is quenched by Au(III)
and No fluorescent is emitted
fsec NIR laser
Au
fluorescence
field enhancement
Local-mode Plasmon Resonance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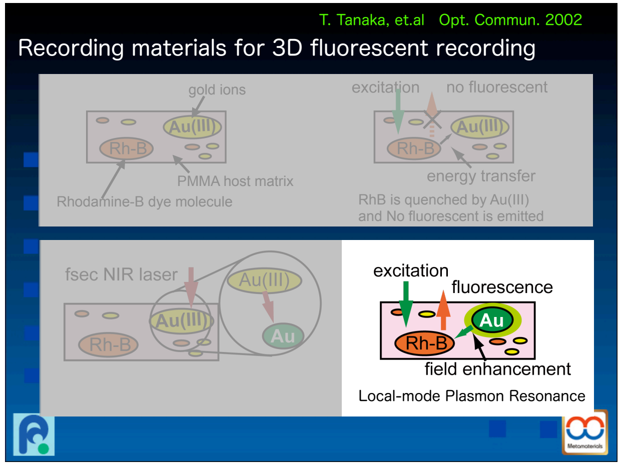
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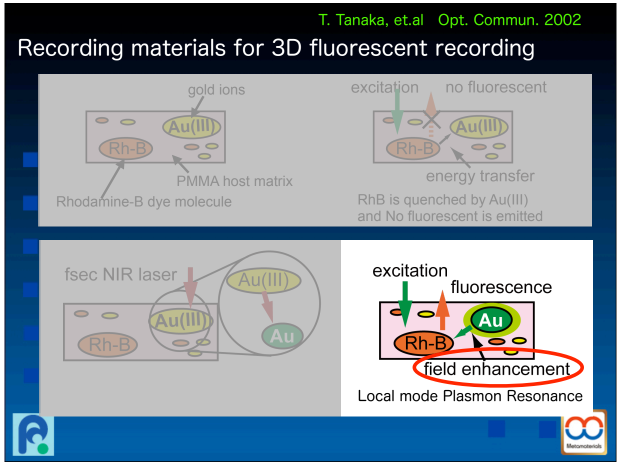
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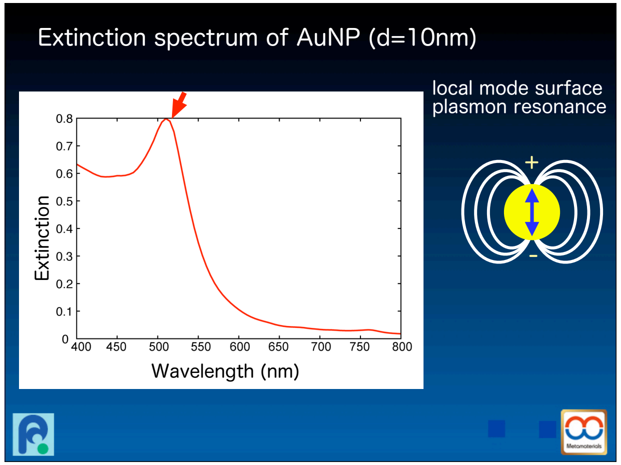
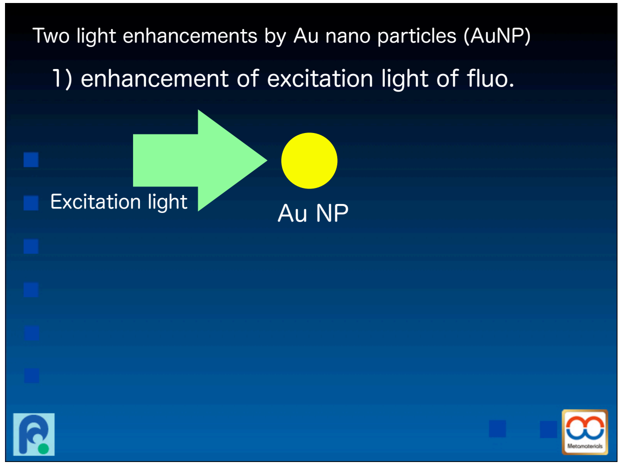
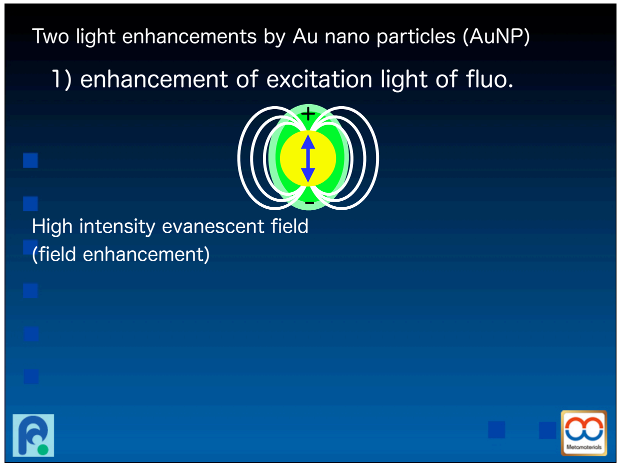
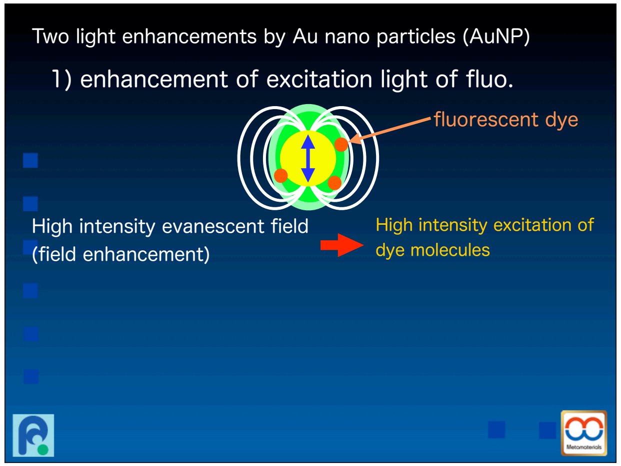
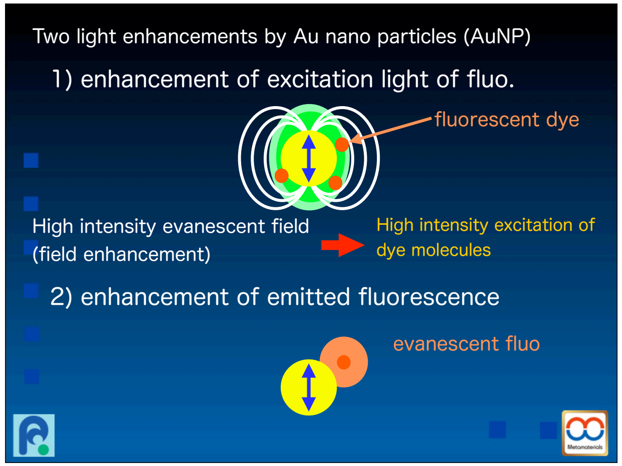

Extinction spectrum of AuNP (d=10nm)
local mode surface
plasmon resonance
Extinction
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
400
450
500
550
600
650
700
750
800
Wavelength (nm)
+
-


Two light enhancements by Au nano particles (AuNP)
1) enhancement of excitation light of fluo.
Excitation light
Au NP

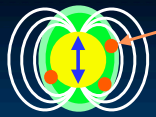

Two light enhancements by Au nano particles (AuNP)
1) enhancement of excitation light of fluo.
+
-
High intensity evanescent field
(field enhancement)


Two light enhancements by Au nano particles (AuNP)
1) enhancement of excitation light of fluo.
fluorescent dye
High intensity evanescent field
(field enhancement)
High intensity excitation of
dye molecules


Two light enhancements by Au nano particles (AuNP)
1) enhancement of excitation light of fluo.
fluorescent dye
High intensity evanescent field
(field enhancement)
High intensity excitation of
dye molecules
2) enhancement of emitted fluorescence
evanescent fluo

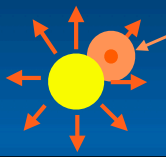
Two light enhancements by Au nano particles (AuNP)

1) enhancement of excitation light of fluo.



High intensity evanescent field (field enhancement) → High intensity excitation of dye molecules

2) enhancement of emitted fluorescence



Recording material

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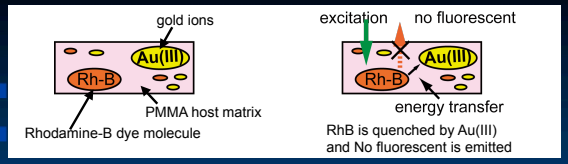
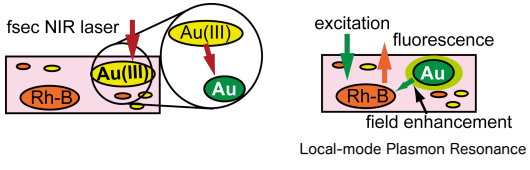
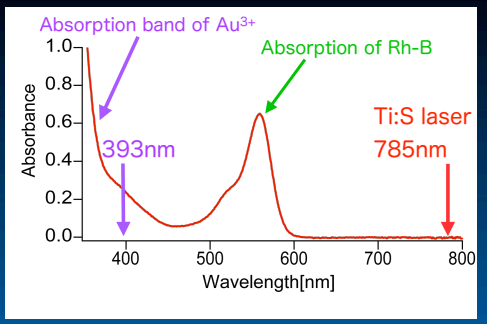


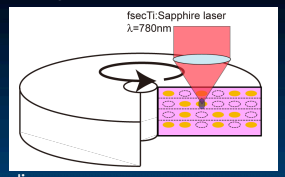


Absorption spectrum



Two-photon absorption

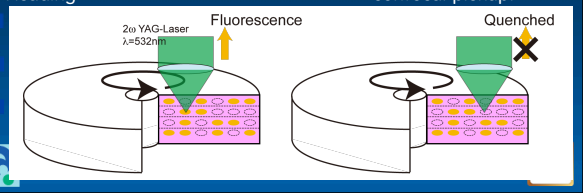
Recording



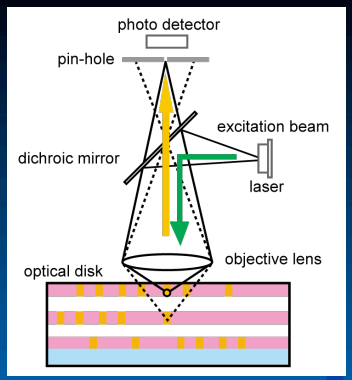
Focusing fsec NIR laser → Record pits as a 3D fluorescent pattern

Reading

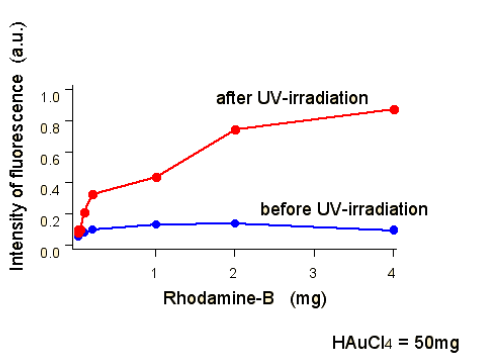
Read out by the confocal pickup.



Confocal read-out



Change of intensity of fluorescence



$HAuCl_4$ = 50mg

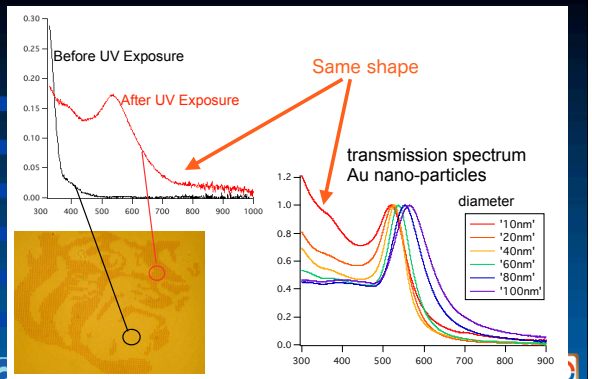
←Fluorescent image

Wavelength : 785nm
Pulse Width : 65fsec
Rep. Rate : 1GHz
Laser Power : 20mW
Objective lens : NA=0.75, 40x
ExposureTime : 100 μsec/dot

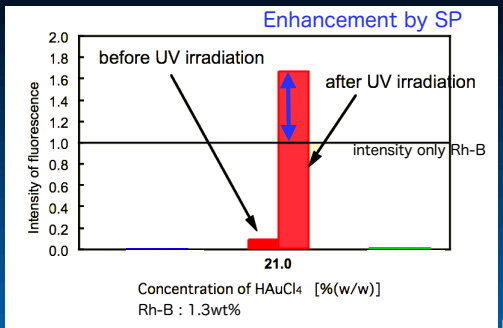
Transmission image→

Faint red color comes from absorption peak of local-mode surface plasmon resonance of gold nano particles

Transmissino spectrum of recorded area



Enhancement by surface-plasmon resonance



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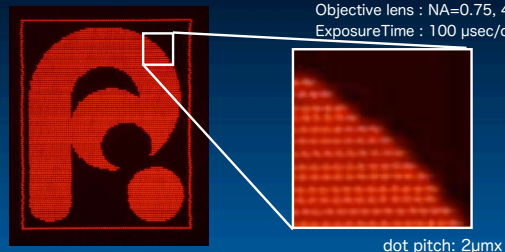
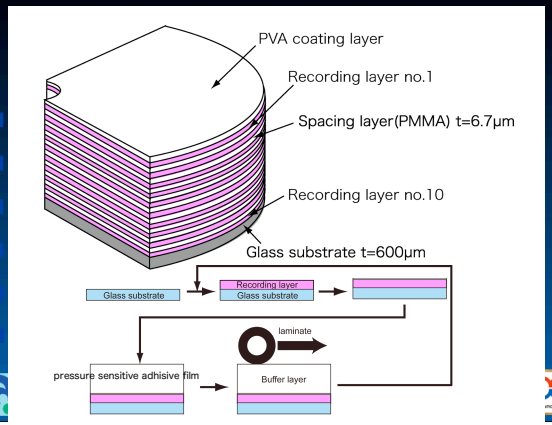


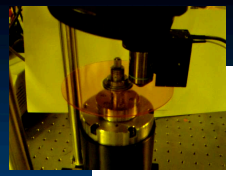
dot pitch: 2μmx 2μm

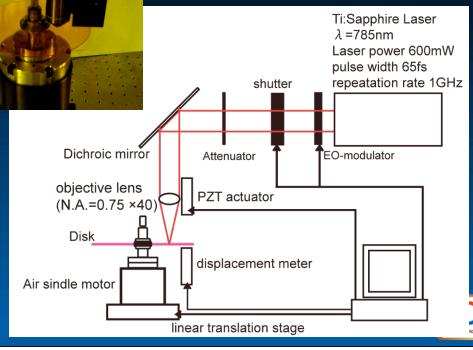
Observed conventional fluorescent microscope

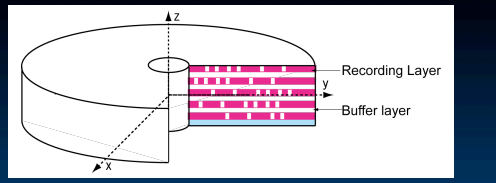
3D fluorescent optical disk with 10 recording layers

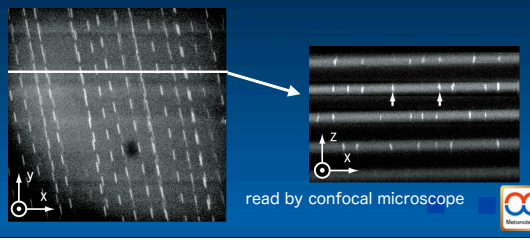


Recording System



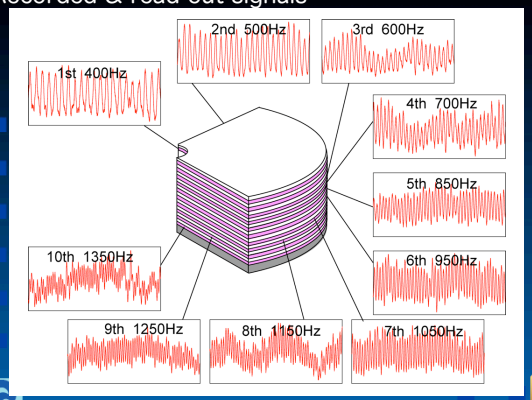




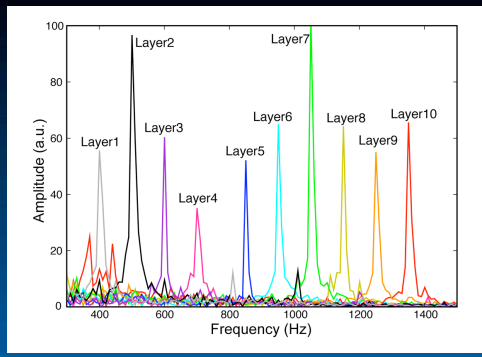


read by confocal microscope

Recorded & read out signals



Fourier spectrum of read signals



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- ○ Signal light comes with different wavelength
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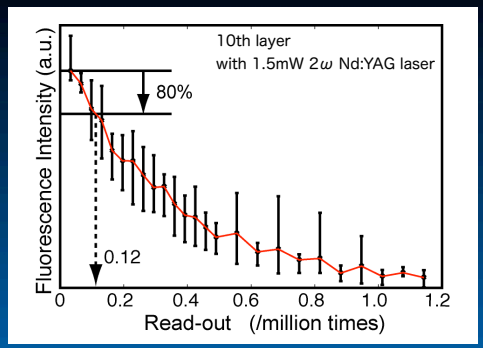
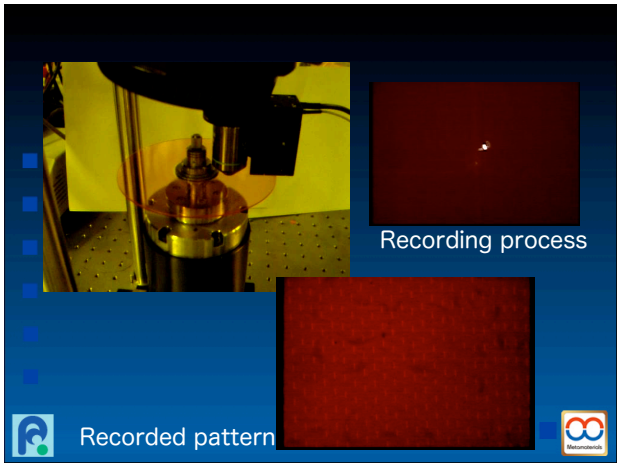
- × Bleaching of fluorescent dye
  - ・Optimization of read-out laser power.

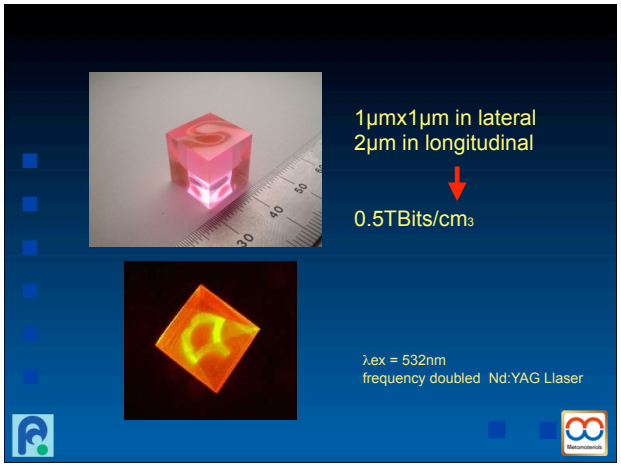
Durability of recorded data

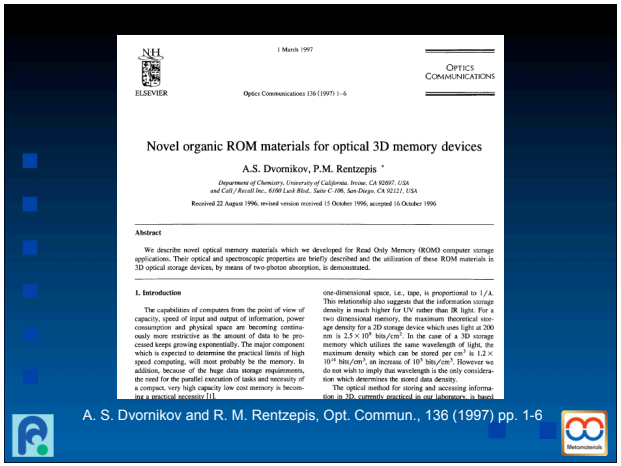


Summary

1. Proposed 3D fluorescent multilayered opical disk
   It can store 3D bit data as fluorescent pattern using the interaction between dye molecules and gold ions/nano-particles.
2. Demonstrated two-photon fluorescent recording and plasmon assisted read-out of 3D data using confocal pickup.
3. Multi-layered optical disk with 10 recording layers and its experimental result are demonstrated.
4. Persistence properties of the recorded data was measured. More than 80% signal intensity was preserved after 0.1M read-out.







1 March 1997

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Optics Communications 136 (1997) 1–6

Novel organic ROM materials for optical 3D memory devices

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Abstract

We describe novel optical memory materials which we developed for Read Only Memory (ROM) computer storage applications. Their optical and spectroscopic properties are briefly described and the utilization of these ROM materials in 3D optical storage devices, by means of two-photon absorption, is demonstrated.

1. Introduction

The capabilities of computers from the point of view of capacity, speed of input and output of information, power consumption and physical space are becoming continuously more restrictive as the amount of data to be processed keeps growing exponentially. The major component which is expected to determine the practical limits of high speed computing, will most probably be the memory. In addition, because of the huge data storage requirements, the need for the parallel execution of tasks and necessity of a compact, very high capacity low cost memory is becoming a practical necessity [1].

one-dimensional space, i.e., tape, is proportional to $1/\lambda$. This relationship also suggests that the information storage density is much higher for UV rather than IR light. For a two dimensional memory, the maximum theoretical storage density for a 2D storage device which uses light at 200 nm is 2.5×10^9 bits/cm^2. In the case of a 3D storage memory which utilizes the same wavelength of light, the maximum density which can be stored per cm^3 is 1.2×10^{15} bits/cm^3, an increase of 10^6 bits/cm^3. However we do not wish to imply that wavelength is the only consideration which determines the stored data density.

The optical method for storing and accessing informa-

tion in 3D, currently practiced in our laboratory, is based

A. S. Dvornikov and R. M. Rentzepis, Opt. Commun., 136 (1997) pp. 1-6