Nano-photonics and Plasmonics in Japan

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Near-field optics, Nano-optics, Plasmonics, Nano-plasmonics, Nanophotonics

↓

Nano-photonics

Area: 378,000km² (Mountain area 80%)
(France) 547,000km²

Population: 127,768,000
(France) 61,680,000

A Brief History of Nanotechnology In Japan

1980's~ Large Scale Integrated Circuits (LSI) Industries

1991 Carbon Nanotube discovered by Dr. Iijima

2000 The National Nanotechnology Initiative (NNI) in USA

2000 Working group of Nanotechnology launched by Nippon Keidanren (Japan Federation of Economic Organizations)

2001 The future society created Nanotechnology ＜n-Plan21>

2002 Nanotechnology Researchers Network Center (MEXT)

Effective support to "***MEXT Nanotechnology Support Project***".

MEXT: (Ministry of Education, Culture, Sports, Science and Technology)

The national budget has been mainly distributed through Japan Science and Technology Agency (JST).

March 27, 2001
Japan Federation of Economic Organizations (Keidanren)

The future society created nanotechnology
<n-Plan21> Outline

Basic Viewpoints in Promotion of Nanotechnology R&D

(1) Innovation of IT, biotechnology, energy & environment technology and materials by means of Nanotechnology

(2) Investment to the Fields, where Japan can be a winner and which has large impacts to Japanese Industry

(3) Proposal of flagship-type projects and challenge-type projects and appropriate distribution of fund including basic research.

(4) Sharing of vision on Nanotechnology and promotion of Nanotechnology strategy in national stage and dynamic promotion of Nanotechnology R&D under the construction of network between Industry, Academia and government.

Important Investment Fields Related to Nanotechnology R&D

(1) Flagship Projects

- ○ R&D focused on practical application and industrialization in the next 5 to 10 years
- ○ Network-type Center of Excellence (COE) operation

◆I T··Developing Low-Power, High-Performance Technology for Building a Ubiquitous Network Society

① Next- generation semiconductor technology

○Transcending design rule limits in semiconductor development

- *Nano-level semiconductor manufacturing/evaluation system*
- *New wiring technology*
- *Devices with new materials and structures*

○ASUKA Project : From 100nm
MIRAI Project : From 70nm

② Terabit-level information storage technology

○Terabit/inch^2 storage density (2010)

- *New materials for storage media and heads*
- *Precision actuators*
- *Magnetic heads with new structures*
- *Near-field optical memory*

③ Network Devices

○Optical : Petabit/second, Wireless: 10gigabit/second(2010)

- *Photonic waveguide devices*
- *Super broadband electronic devices*

(2) Challenge to Future Projects

- ○ Targeted R&D revolving around developing innovative basic technology
- ○ Network-type COE operation
- ○ Well-timed practical application (including nurturing venture businesses)

① Nano processes and materials

Two main researchers of Nano-photonics in Japan

Professor Motoichi Ohtsu:

University of Tokyo

Professor Satoshi Kawata:

Osaka University

RIKEN (The Institute of Physical and Chemical Research)

***Japan Science and Technology Agency* (*JST*)**

The aim of JST is to establish Japan as a nation built on the creativity of science and technology.

Ohtsu Localized Photon Project (Tokyo)	
Theory Group	Tenko Bldg. (Machida)
Nano-Photonics Group	Tenko Bldg. (Machida)
Atom-Photonics Group	Tenko Bldg. (Machida)

Kitano Symbiotic Systems Project (ToKyo)	
Systems Biology Group	Mansion 31 (Tokyo)
Symbiotic Intelligence Group	Mansion 31 (Tokyo) Caltech (California)

Kusumi Membrane Organizer Project (Nagoya)	
Molecular Interaction Group	Kumazaki Bldg. (Nagoya)
Membrane Skeleton Function Group	Kumazaki Bldg. (Nagoya)
Cell-Cell Interation Group	Kumazaki Bldg. (Nagoya)

Kondoh Differentiation Signaling Project (Kyolo)	
Cell Interactions Group	Kinki Invention Center (Kyoto)
Developmental Mutants Group	Kinki Invention Center (Kyoto)
Differentiation Transition Group	Kinki Invention Center (Kyoto)

Tarucha Mesoscopic Correlation Project (Atsugi, Kanagawa)	
Supoerstructure Correlation Research Group	NTT-Atsugi Research Development Center
Heteroo-system Correlation Research Group	NTT-Atsugi Research Development Center
Quantum Transport Research Group	Delft University of Technology (Holland)

ERATO-type (Exploratory Research for Advanced Technology)

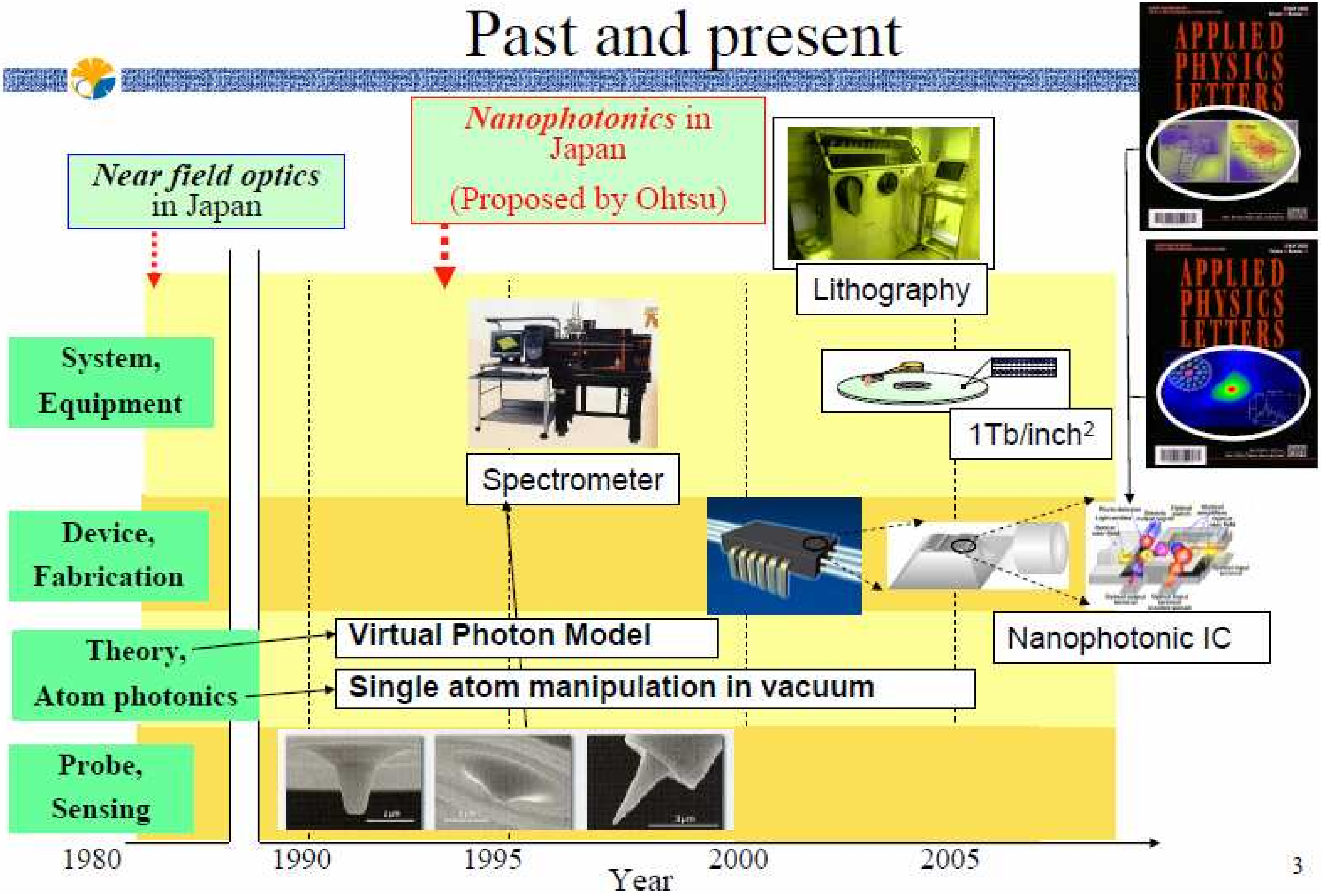
Localized Photon Project, (1998-2003), $8.3 million,

Project Leader: ***Prof. M. Ohtsu*** (Tokyo University)

SORST-type (Solution-Oriented Research for Science and Technology). Research projects of the SORST program are selected among projects with high expectations of outstanding results and of extraordinary developments in CREST-type, ERATO-type and other projects. Above ***Localized Photon Project*** has been selected as the following project:

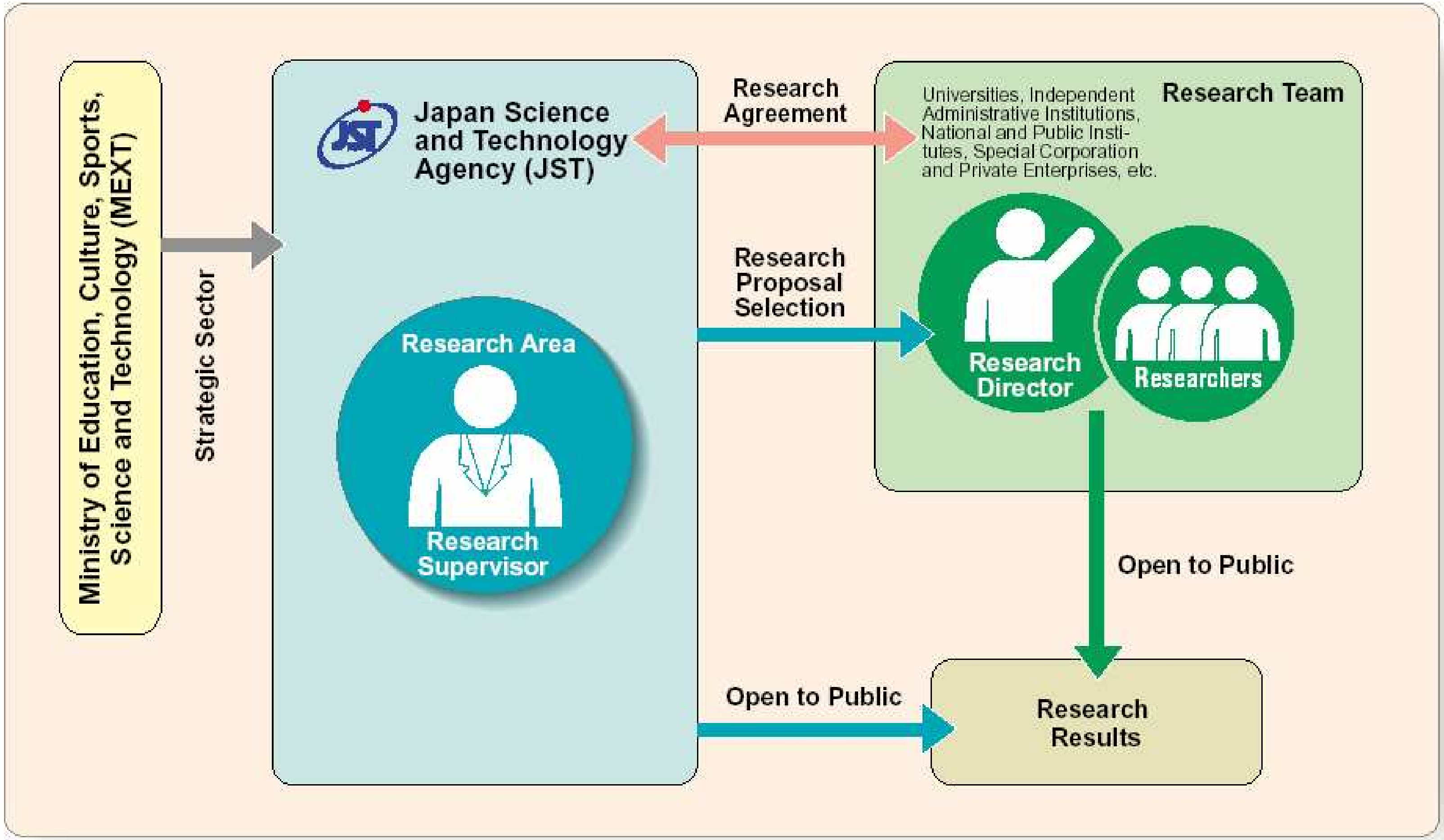
Nanophotonics Team, (2003-2008), $2.5 million, Project Leader: ***Prof. M. Ohtsu*** (Tokyo University)

Past and present



Outline of CREST

After proposal invitation and selection, JST promotes the basic research by concluding Research Agreements with the research institutes which researchers belong to.



CREST-type

(Core Research for Evolutional Science and Technology: Team type research)

FY2006

Plasmonic Scanning Analytical Microscope

Satoshi Kawata
Professor, Osaka University

We propose to develop a new analytical nanoscope that uses surface plasmon polaritons (SPPs) as a nano-probe. SPPs are collective oscillation of electrons excited locally in metal nano structures. Our microscopy uses 1) locally enhanced electromagnetic field provided by SPPs and 2) perturbation of optical responses induced by the mechanical interactions between the probe and the sample with typical probe-applied force of the order of nano-Newton, which enables one to perform nano-analysis and imaging of nano-materials.

Studies of Semiconductor Quantum Structures and Exploration of Terahertz Technology

Susumu Komiyama
Professor, The University of Tokyo

A sensitive passive method of detecting extremely weak terahertz waves emitted from objects without external illumination is developped by ingeniously exploiting semiconductor quantum structures. Beyond characterization of matters, the method makes it possible to investigate phenomena and their

Development of Laser assist Three-dimensional Atom Pro Applications for Device Anal

Kazuhiro Hono
Fellow, National Institut

To broaden the applications of the thr probe (3DAP) technique for mapping re tions for a wide variety of materials, th of the conventional 3DAP that stem fror process will be overcome by using puls evaporation. A newly developed lase 3DAP will be applied to nanostructure and semiconductor materials and their metallic materials that used to be impo the voltage pulsed 3DAP. At the same t ration techniques that will make it possi areas of various types of materials will

Development of a Multi-func Sum Frequency Microscope

Goro Mizutani
Professor, Japan Advanced Institute of S

When a medium is irradiated with light frequencies, it radiates another light f quency. In an optical sum frequency light field is focused on a two-dimension

Creation and simulation of optoelectronics function in nanometer space

Hirokazu Hori

University of Yamanashi, Professor

Website of Lab

This research is aiming at creation of nano-photonics devices for innovative information processing and signal transfer systems by means of controlling coupled system of electrons with optical fields in nanometer-sized space. Simulation is developed for design and analysis of optoelectronic processes in spin-chain-controlled nanophotonics device and its fabrication processes by nano-photolithography. Based on expermental research of atomic/molecular level, this project will open up new field of nano-optoelectronics.

Main Research Collaborators list

Shinichi Oishi	Waseda University	Faculty of Science and Engineering	Professor
Kiyoshi Kobayashi	Tokyo Institute of Technology	Graduate School of Science and Engineering	Professor
Makoto Naruse	National Institute of Information and Communications Technology	Photonic Network Group	Senior Principle Investigators
Kazuo Kitahara	International Christian University	Division of Natural Sciences, College of Liberal Arts	Professor
Masaru Tsukada	Waseda University	Faculty of Science and Engineering	Professor
Hitoshi Nejoh	National Institute for Materials Science	Nano System Architecture Group, Nano System Function Center	Senior Principle Investigators

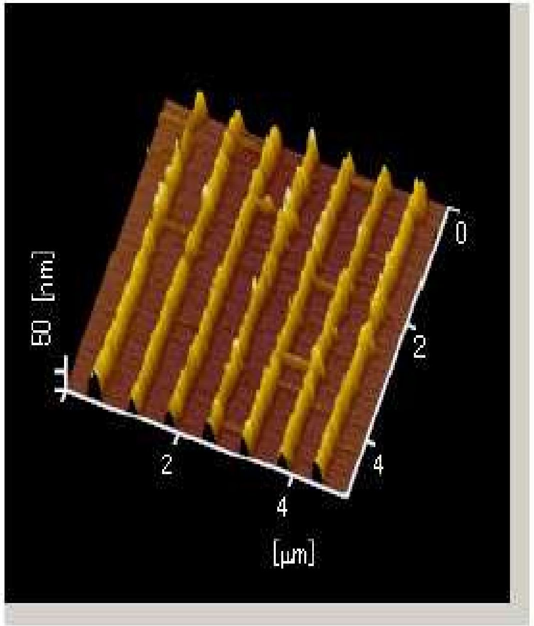
Ultrahigh Capacity Storage Technology Project,

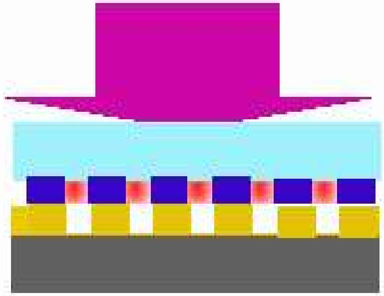
Ministry of Economy,Trade & Industry (METI) (2003-2007), 26 M USD

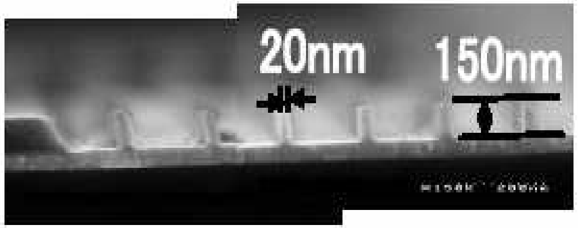
(*Hitachi, Toshiba, Fujitsu, Ricoh, SII, Hitachi-Maxell, Konica-Minolta, Pioneer*)

Exhibited at
International Trade Expo 2005

Near field optical lithography, Ministry of Education (2005-2007), 2.5 M USD (Canon)







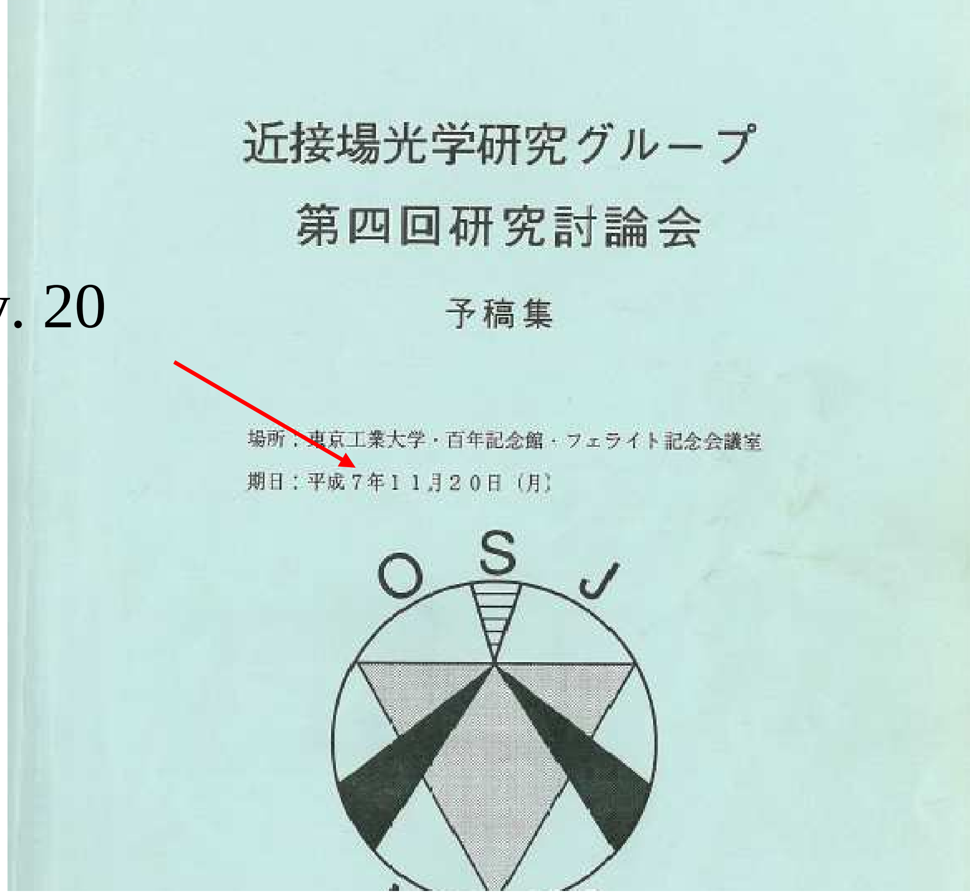
Proto-type of a commercial product

Resolution 20- 50 nm （5mm□）

1m x 1m x 1m

Academic Activities: Domestic 1

1995, Nov. 20



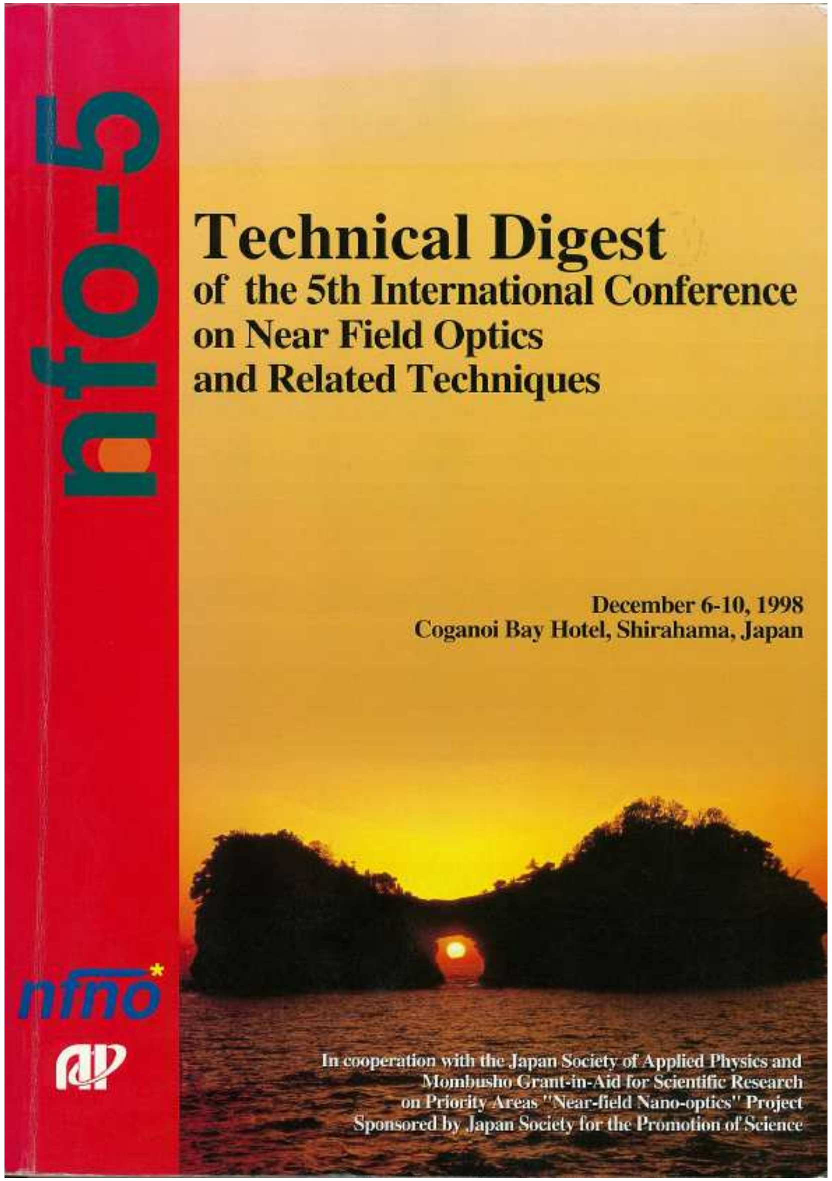
Technical group of Optical Near-Fields in Optical Society of Japan and Japan Society of Applied Physics. This group has organized symposium every year for 1994-2004.

The group has changed name as ***Technical Group of Nano-Optics*** in 2004 and has organizes symposium every year since 2004.

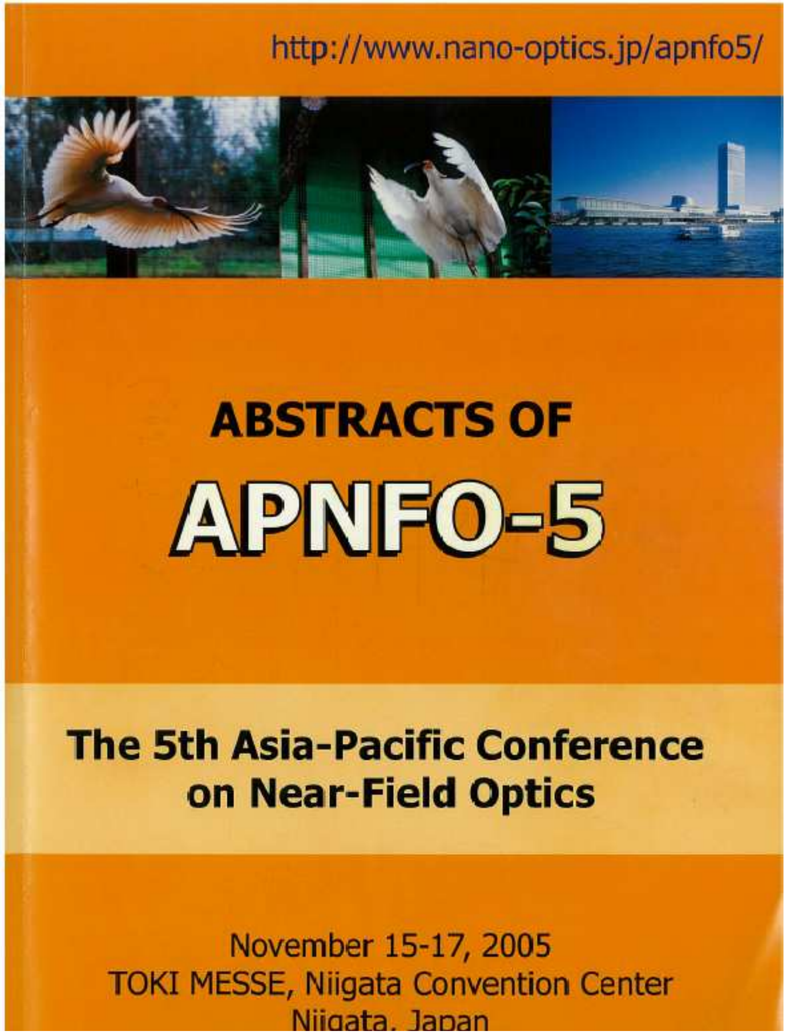
Academic Activities: Domestic 2

Plasmonics Symposium in Japan Society of Applied Physics.
This symposium has been held every year since 2003.

Academic Activities: International 1

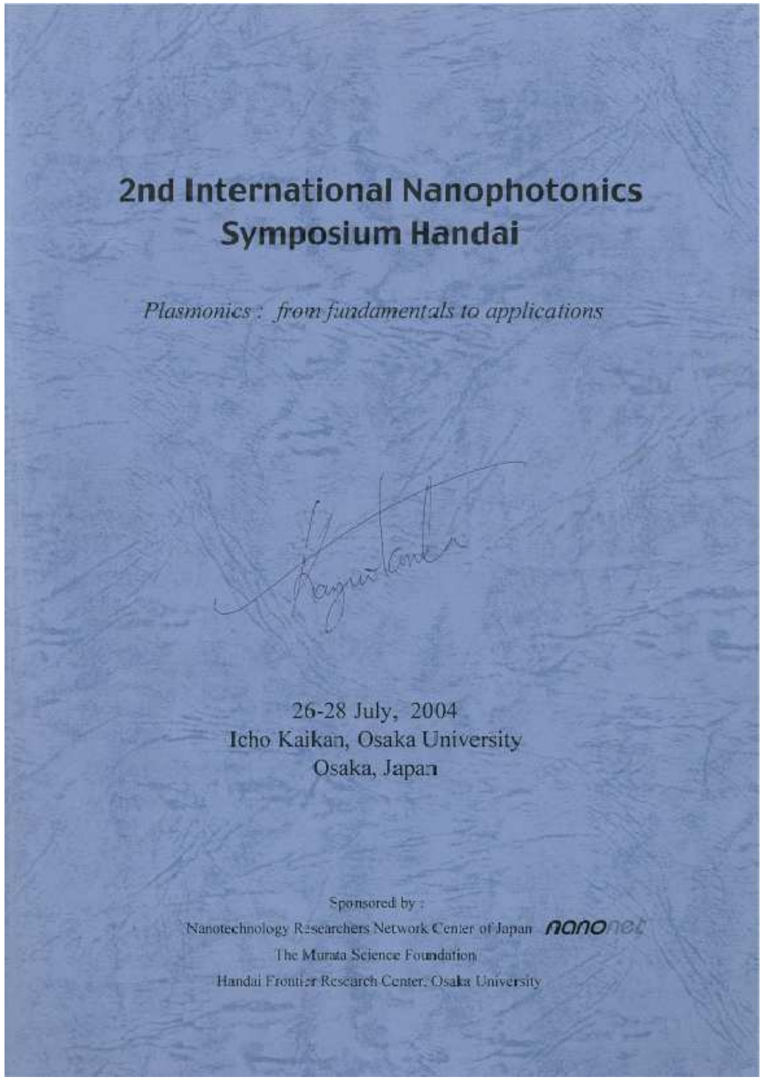


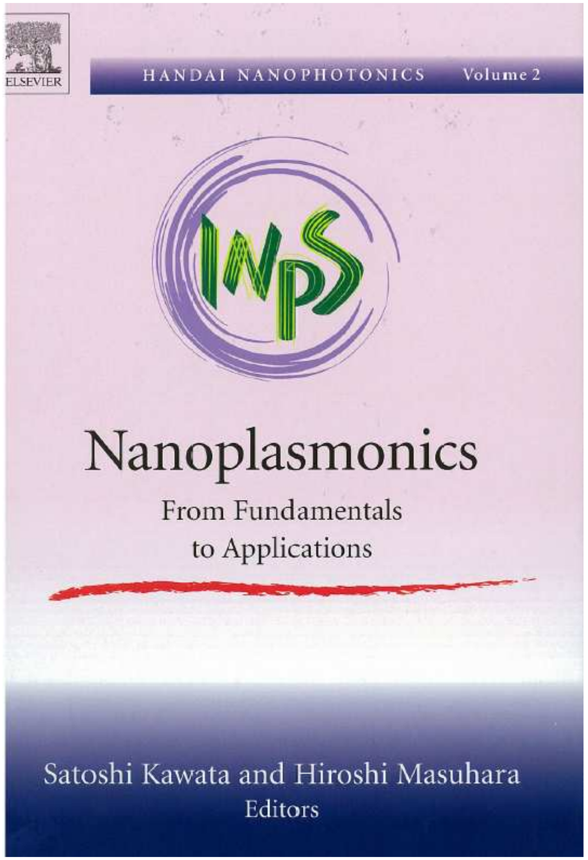
Academic Activities: International 2



***Asia Pacific Workshop on Near Field Optics* (*APNFO*):** This workshop has been held from 1996 to present in following places:
1st: Seoul, 2nd: Beijing, 3rd: Melbourne, 4th: Taroko, 5th: Niigata, 6th:Yellow Mountain.

Academic Activities: International 3





***The International Nanophotonics Symposium Handai* (*INSH*):** This symposium has been held in 2004 and 2006 at Osaka University (Japanese name HANDAI).

Appl. Phys. B 84, 243–246 (2006)
DOI: 10.1007/s00340-006-2234-x

Applied Physics B
Lasers and Optics

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K. AKAHANE[3]
M. NARUSE[3]
N. YAMAMOTO[3]
M. OHTSU[1,4]

Demonstration of nanophotonic NOT gate using near-field optically coupled quantum dots

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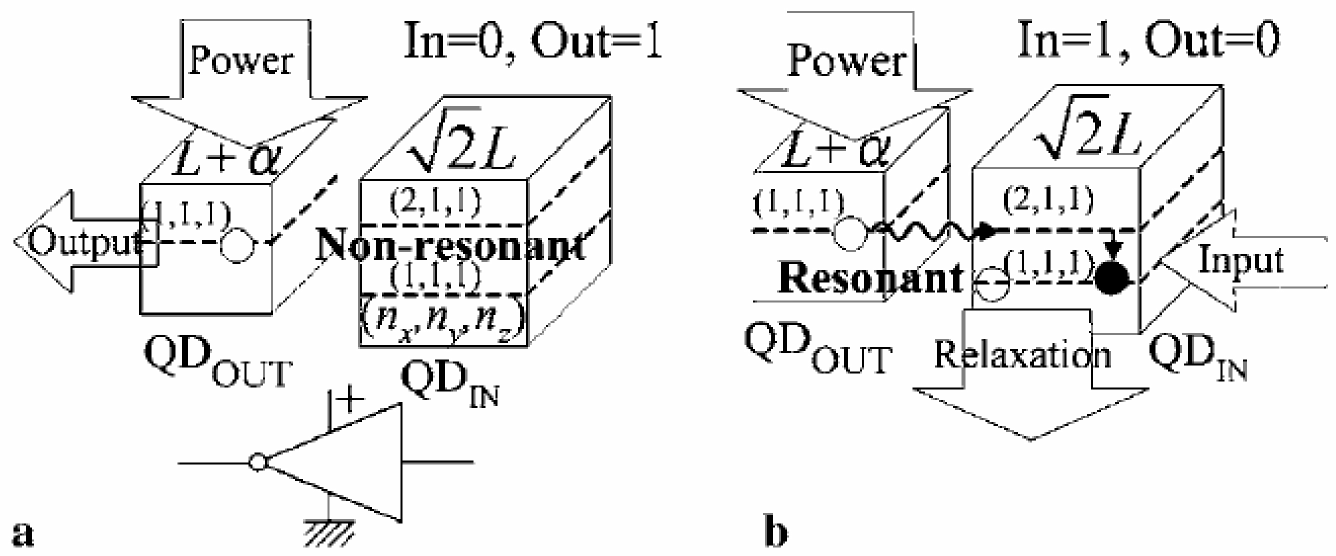
[2] Department of Physics, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan
[3] National Institute of Information and Communications Technology, Koganei, Tokyo 184-8795, Japan
[4] Department of Electronics Engineering, University of Tokyo, Bunkyo-ku, Tokyo 113-8656, Japan



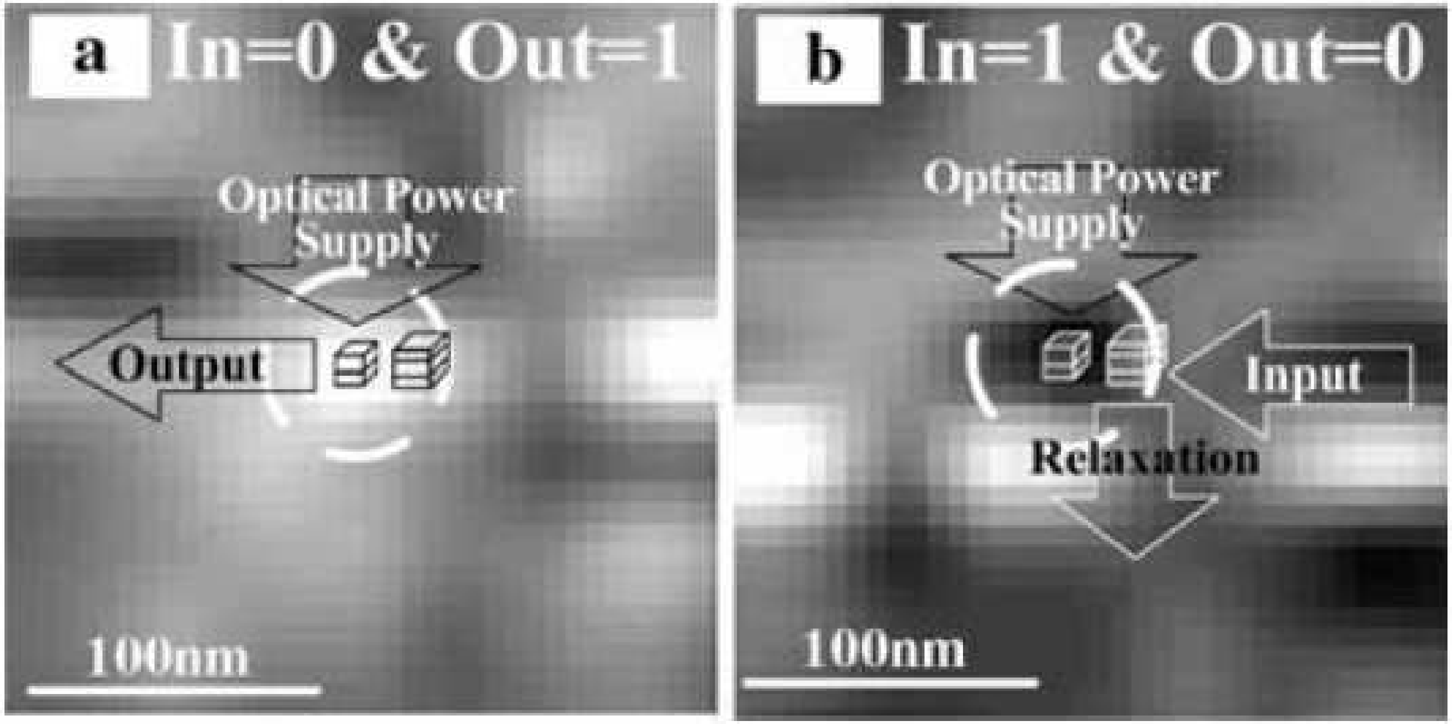
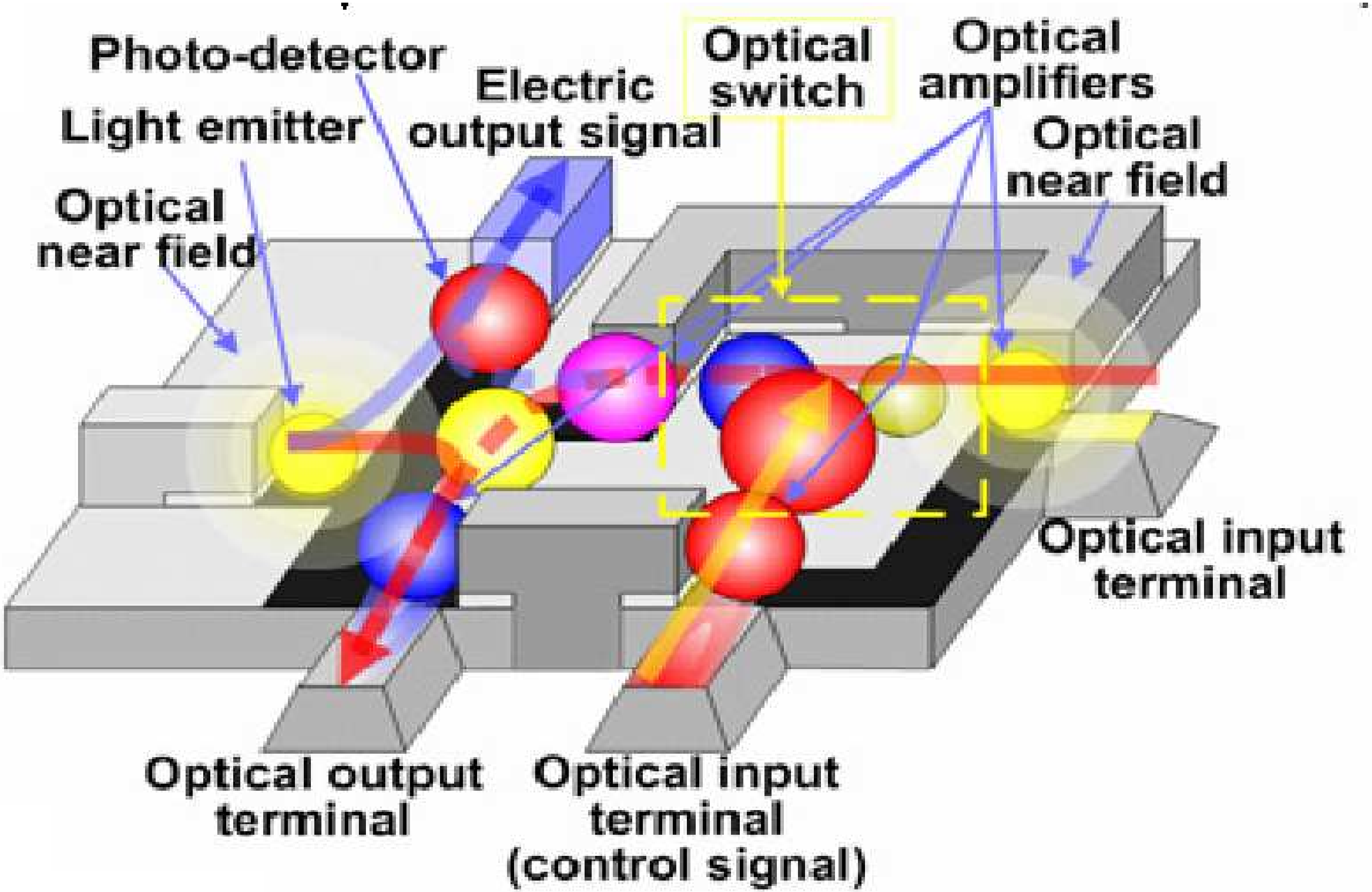


FIGURE 2 The spatial distribution of the output signal from a nanophotonic NOT gate measured using a near-field microscope at Input = 0 (**a**) and Input = 1 (**b**)

Future Nanophotonic Integrated Circuits proposed by Ohtsu's Group



Topics of Nano-photonics in Japan　2

Signal Characteristics of Super-Resolution Near-Field Structure Disk in Blue Laser System

Jooho Kim*, Inoh Hwang, Hyunki Kim, Duseop Yoon, Insik Park, Dongho Shin, Yunchang Park[1] and Junji Tominaga[2]

Digital Media R&D Center, SAMSUNG ELECTRONICS CO., LTD, Suwon 442-742, Korea
[1] Analytical Engineering Center, Samsung Advanced Institute of Technology, Kihung, Yongin 449-712, Korea
[2] Center for Applied Near-Field Optics Research, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba 305-8563, Japan

(Received December 8, 2003; accepted February 17, 2004; published July 29, 2004)

Abstract:

We report the signal characteristics of a super-resolution near-field structure (super-RENS) disk in a blue laser system (laser wavelength, 405 nm; numerical aperture (NA), 0.85). By introducing a new structure for the blue laser system, a 42.5 dB carrier to noise ratio (CNR) at a 50-nm-mark-length-signal (which is equivalent to a 75 GB capacity with a 0.32 micrometer track pitch and a 1–7 modulation code (Blu-ray disc (BD) format)) and a much higher readout-stability were obtained. Transmission electron inicroscope (TEM) image analysis revealed that the new blue structure has clear diffusion protection barriers produced by continuous Pt particles, which is related to higher CNR and readout stability characteristics.

First Generation Super-RENS

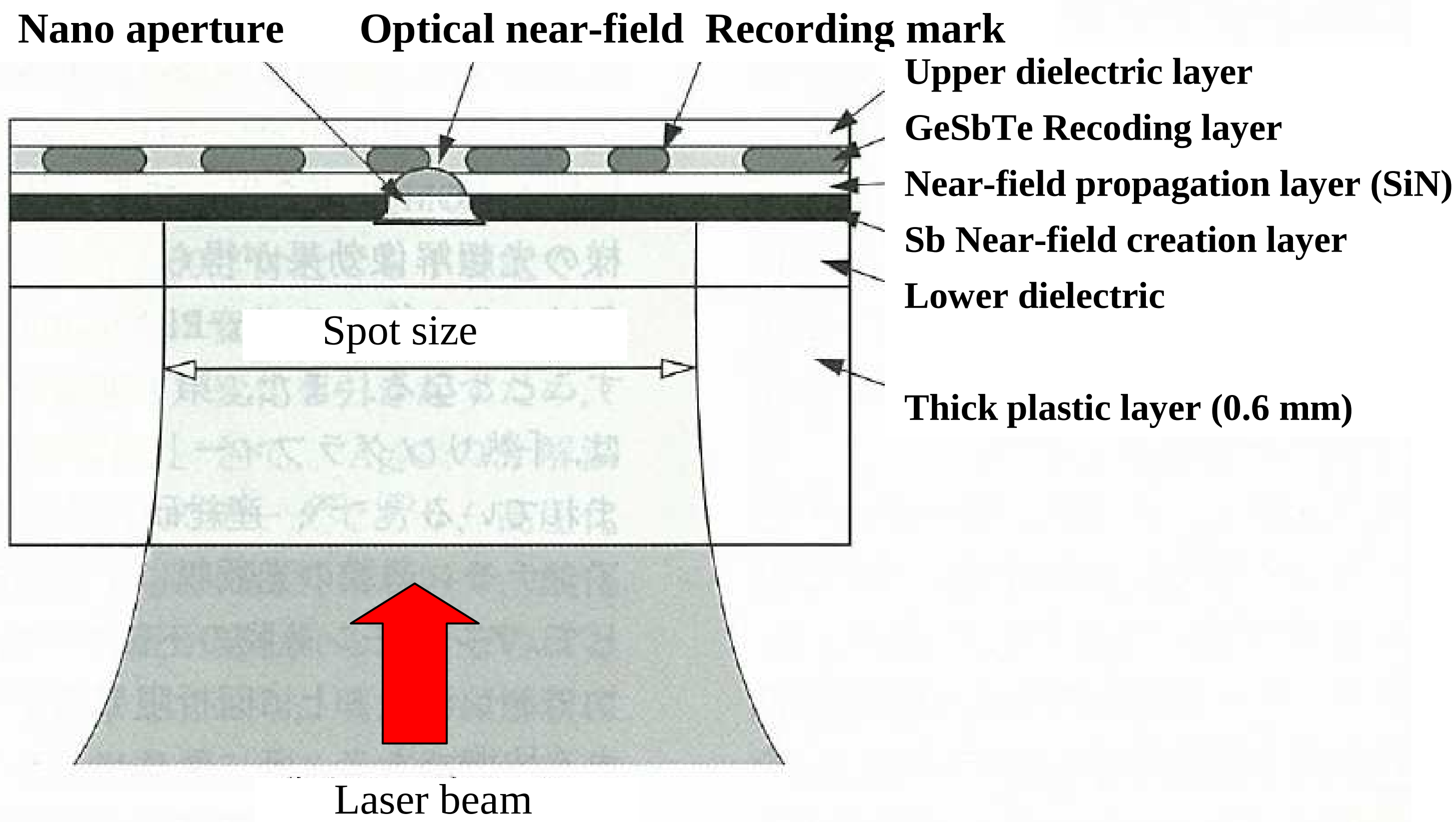


図１　第１世代 Super-RENS 光ディスクの構造　　Sb 近接場光発生層／近接場光伝搬層／ GeSbTe 記録層を特に Super-RENS 機能層と呼ぶ．レーザは基板を透かして入射され，Sb 層に発生する光学的微小開口で絞られるが，このとき近接場光が発生する．近接場光は SiN でできた伝搬層（厚さ 20 ～ 40nm）を透かして記録層に記録された結晶ーアモルファスの情報パターンを読み出す．Super-RENS 光ディスクは，約 800 ～ 2,400rpm で回転する．

Topics of Nano-photonics in Japan 3

2004

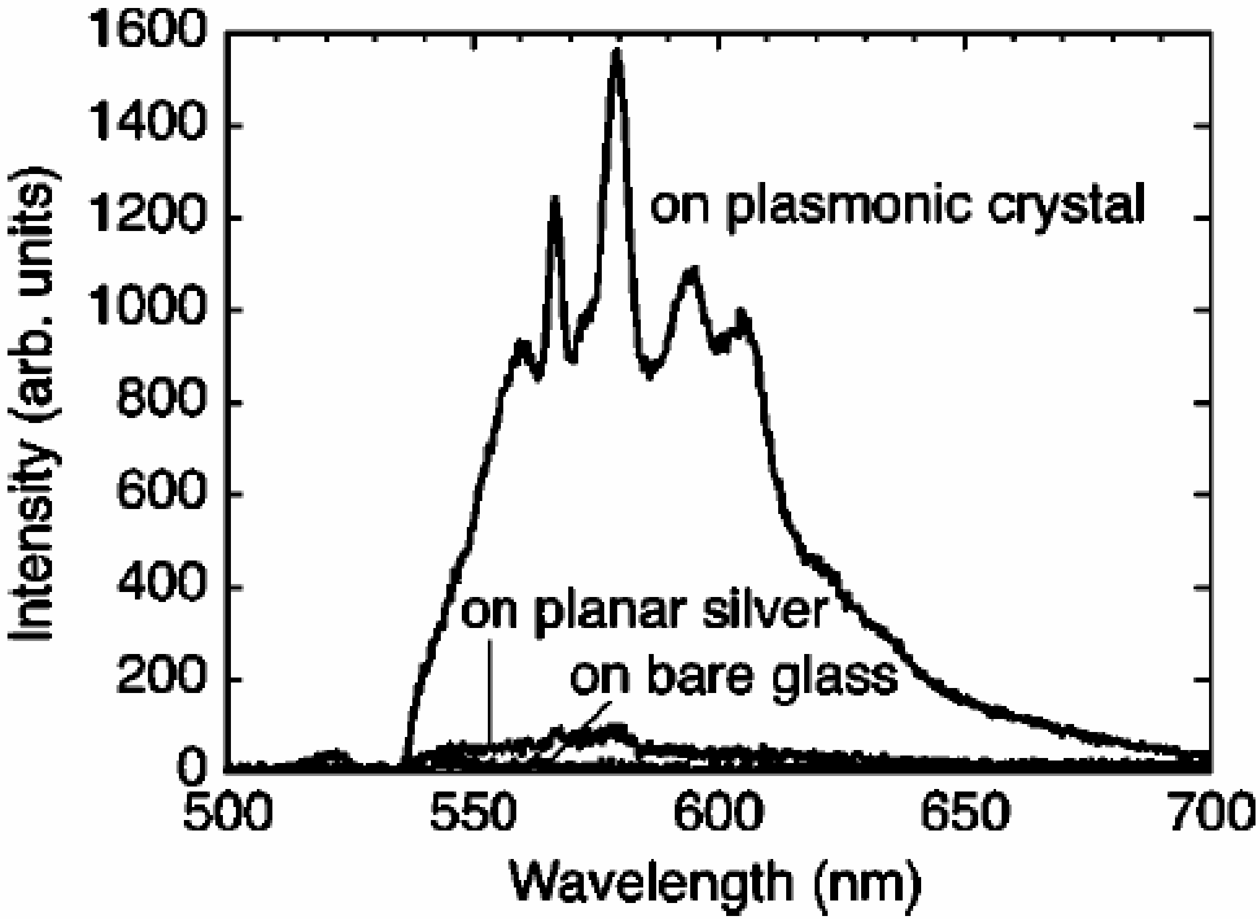


FIG. 3. Fluorescence spectra of a methyl-red doped PMMA film deposited on a bare glass substrate, on a planar silver surface, and on a 507 nm pitch plasmonic crystal.

Simulation of practical nanometric optical circuits based on surface plasmon polariton gap waveguides

Kazuo Tanaka, Masahiro Tanaka, and Tatsuhiko Sugiyama

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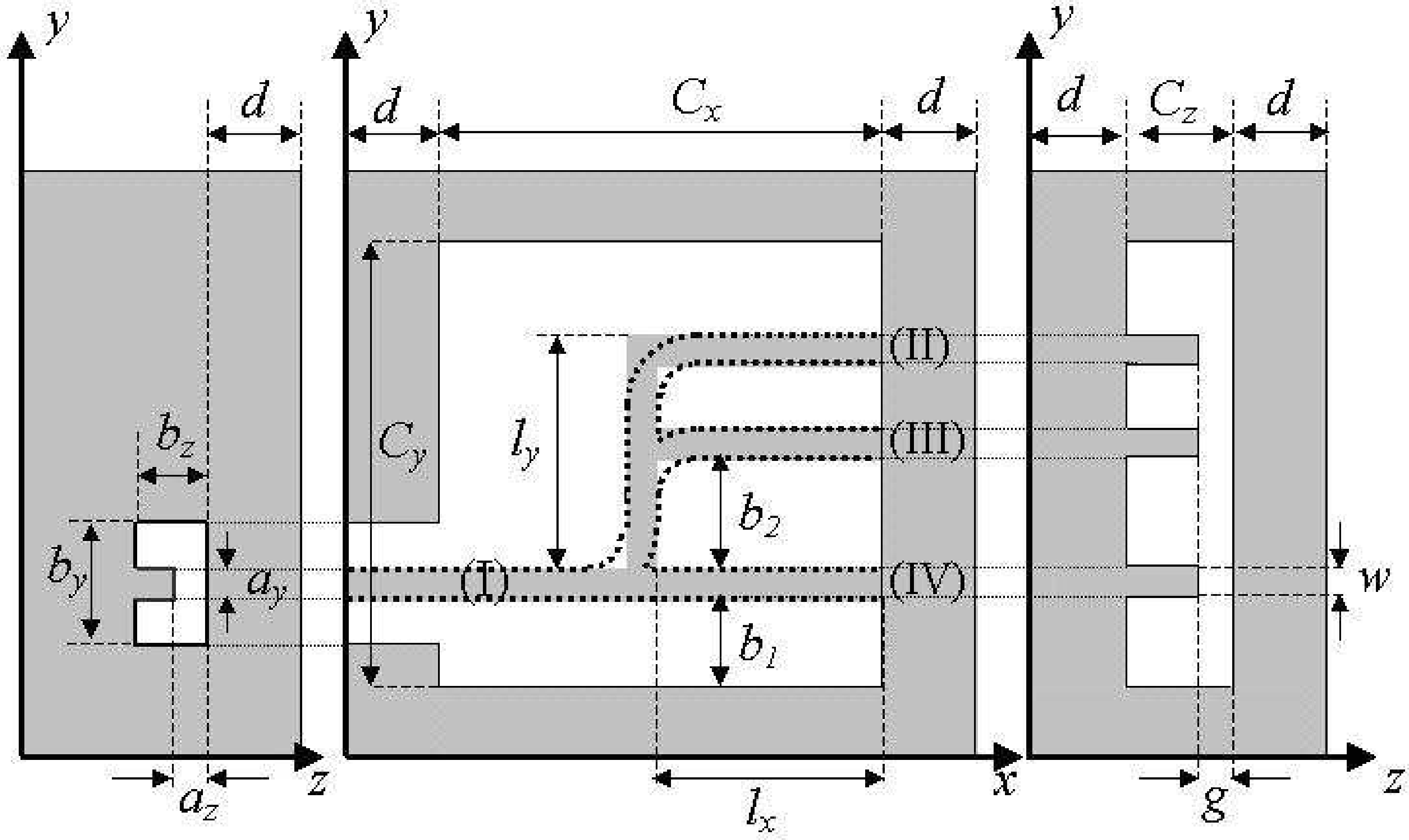
Abstract: The feasibility of nanometric practical optical waveguide circuits based on surface plasmon polariton gap waveguides (SPGWs) is investigated in detail through three-dimensional simulations. H-plane planar branching waveguide circuits of subwavelength scale are shown to be possible using SPGWs. The waveguide characteristics of the circuits are found to be highly sensitive to the dimensions of the optical circuit, indicating that highly accurate computer-aided design and simulations are necessary for the construction of practical SPGW-based optical circuits.

OCIS codes: (240.6680) Surface plasmons; (250.5300) Photonic integrated circuits; (000.4430) Numerical approximation and analysis

References and Links

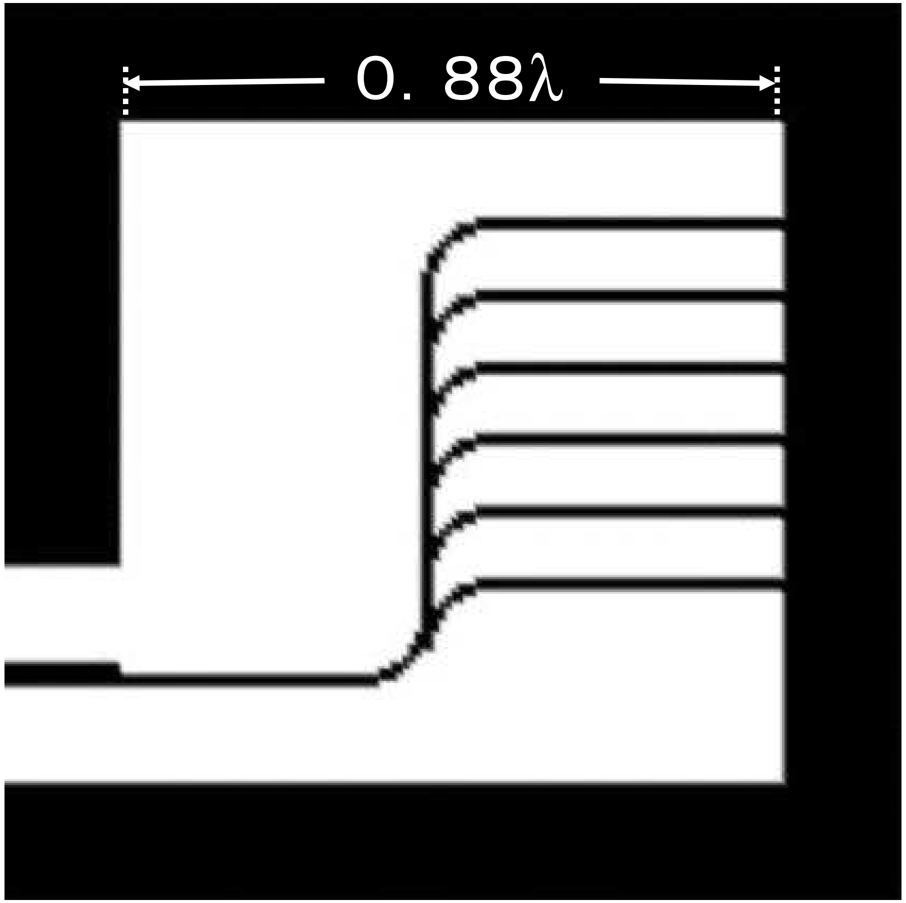
Simulation of practical nanometric optical circuits based on surface plasmon polariton gap waveguide, *Optics Express* **13**, 256-266 (2005)

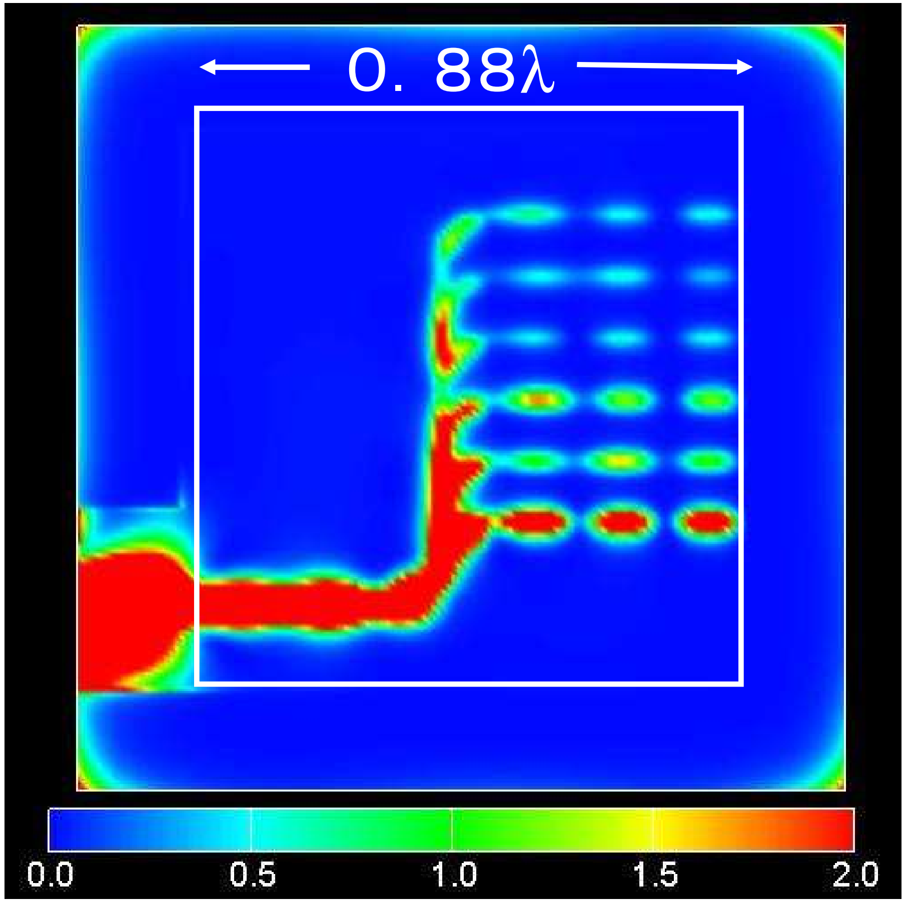
Nanometric optical circuits using Surface Plasmon Polariton



λ= 573 nm, ε_1= –12.4 – j0.85 (Silver) ε_2 = 2.25 (Free space)

Dense and Complicated Nanometric Optical Circuits





Simulation of practical nanometric optical circuits based on surface plasmon polariton gap waveguide, *Optics Express* **13**, 256-266 (2005)

APPLIED PHYSICS LETTERS **87**, 151116 (2005)

Metallic tip probe providing high intensity and small spot size with a small background light in near-field optics

Kazuo Tanaka,[a] Masahiro Tanaka, and Tatsuhiko Sugiyama
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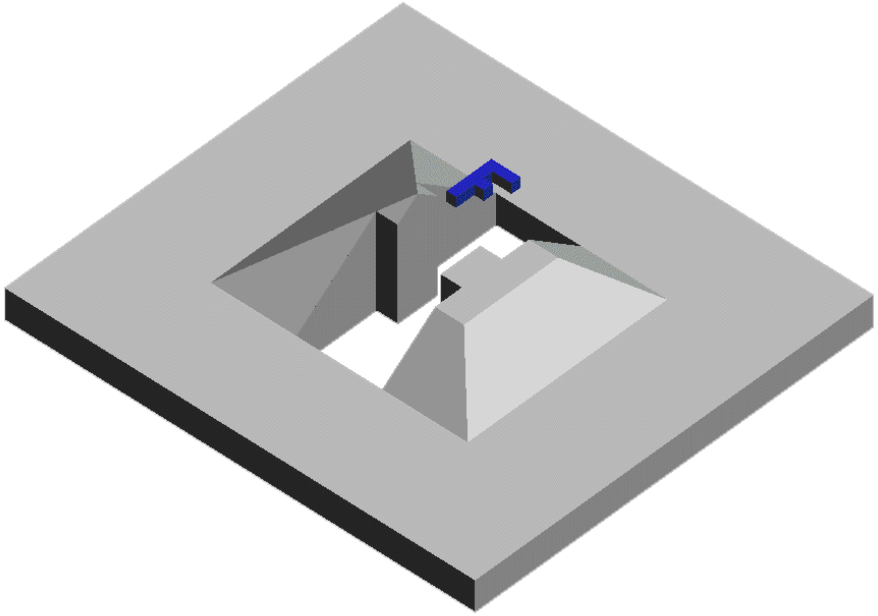
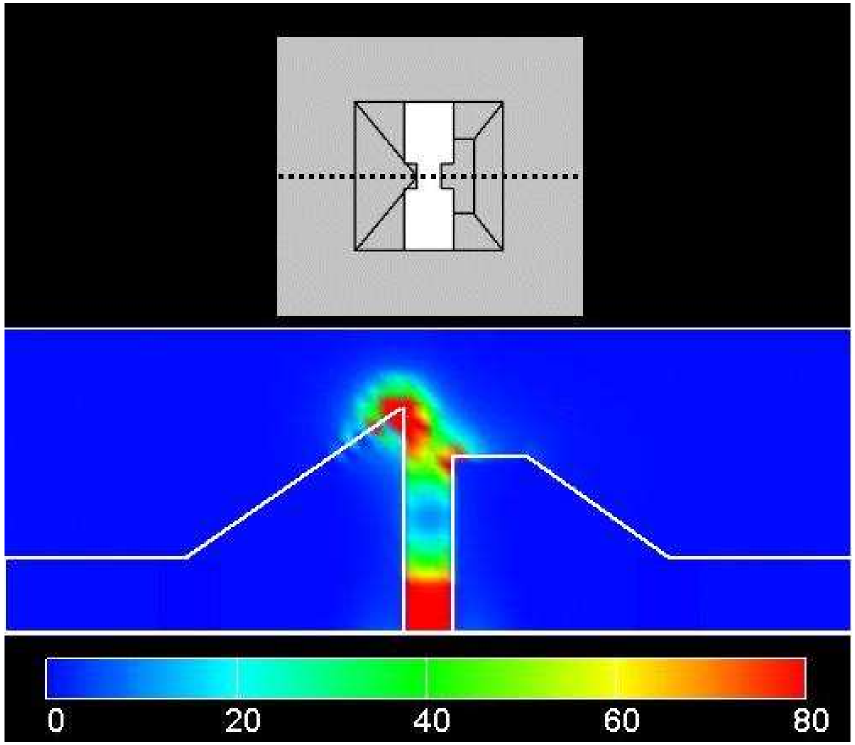
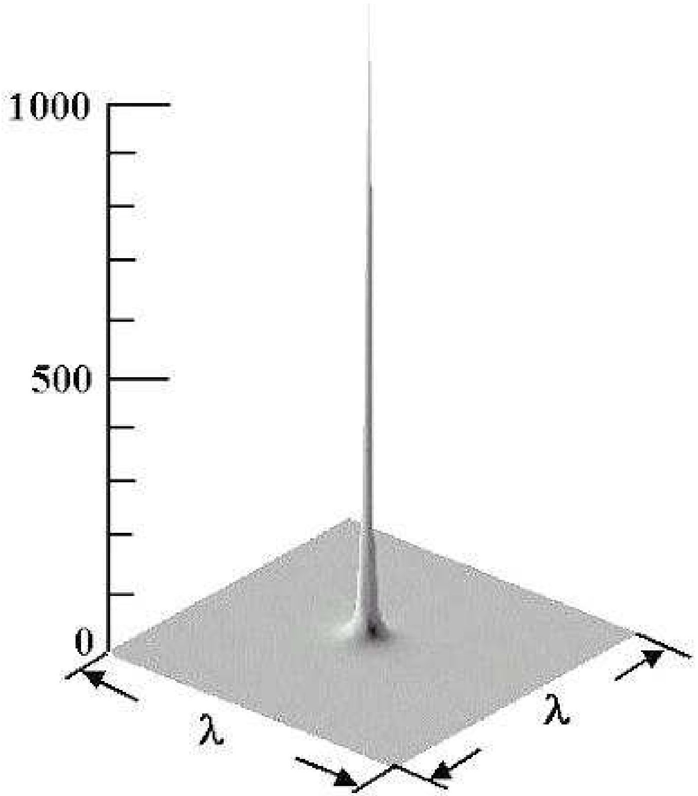
(Received 16 December 2004; accepted 22 August 2005; published online 7 October 2005)

A metallic tip probe that gives high optical intensity and small spot size with a small background light is proposed and simulated. The proposed tip probe provides advantages of both the aperture probe and the apertureless probe currently used in the scanning near-field optical microscope. The tip probe is illuminated by surface plasmon polaritons transmitted through the I-shaped aperture in a pyramidal structure on a thick metallic screen. Scattering of optical waves by this structure is solved numerically using a volume integral equation by generalized conjugate residual iteration and fast Fourier transformation. The proposed tip probe is shown to simultaneously provide both high near-field intensity and small spot size with a small background light. [DOI: 10.

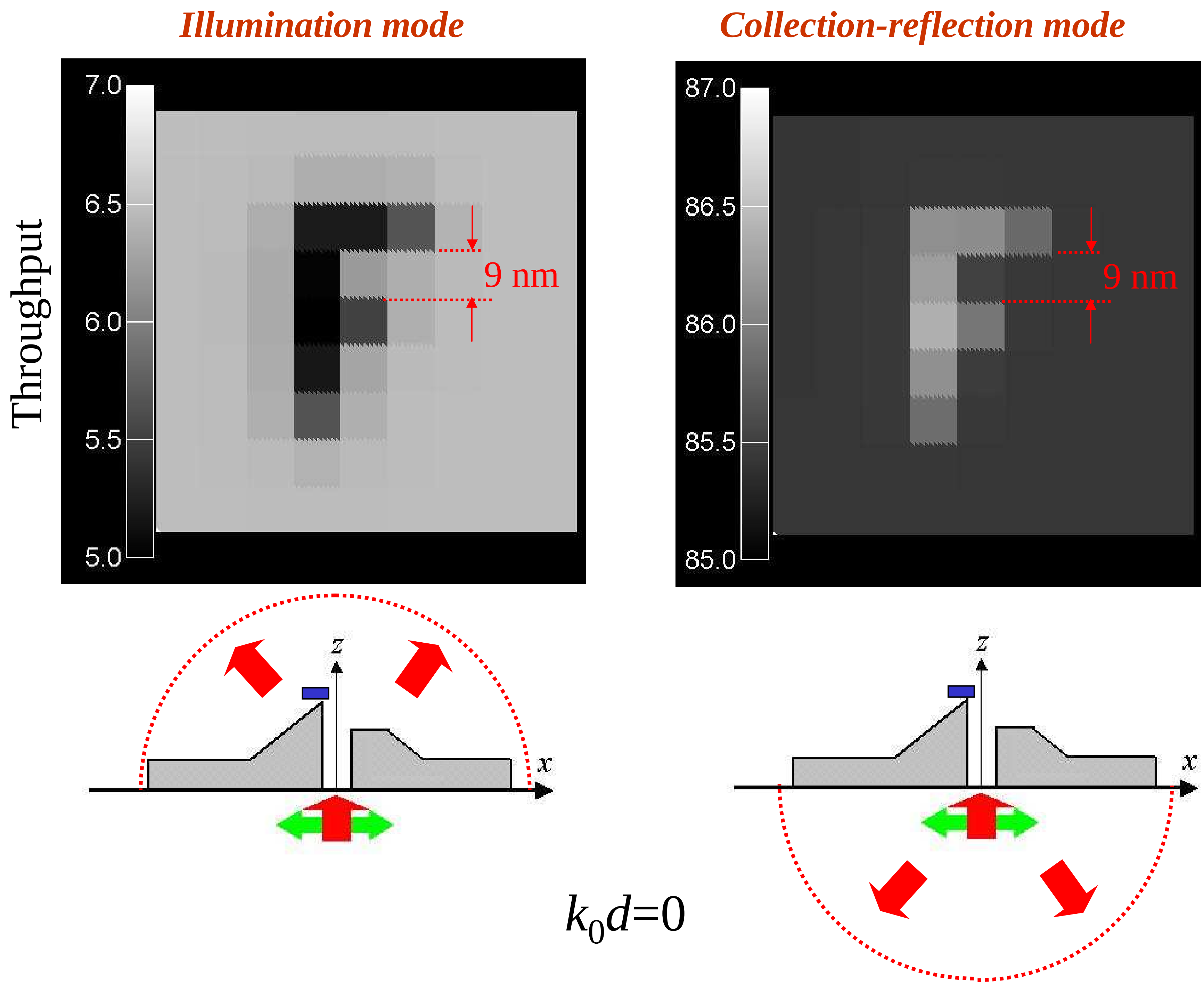


Creation of strongly localized and strongly enhanced optical near-field on metallic probe-tip with surface plasmon polaritons, *Optics Express* **14**, 832-846 (2006)



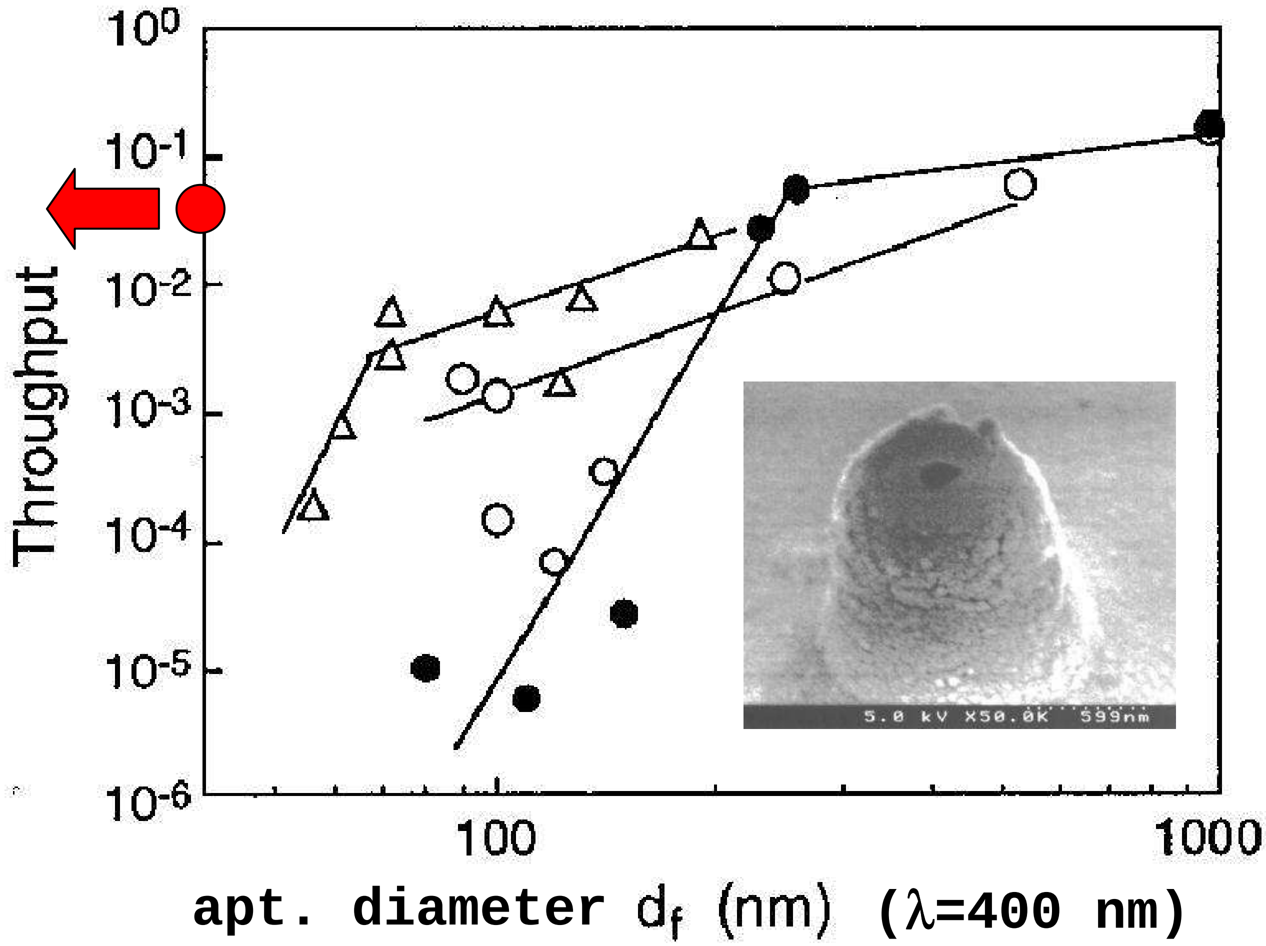


λ= 573 nm, ε_1= –12.4 – j0.85 (Silver) ε_2 = 2.25 (Free space)

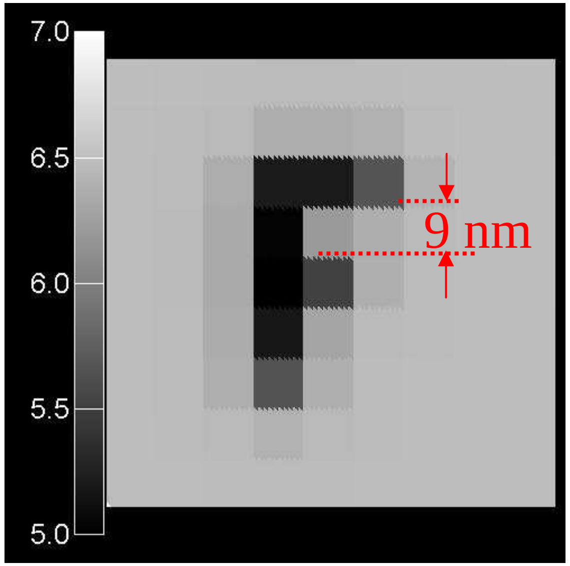


Illumination mode
Collection-reflection mode
Throughput
7.0
6.5
6.0
5.5
5.0
87.0
86.5
86.0
85.5
85.0
9 nm
9 nm
z
x
z
x

$k_0d=0$



Illumination mode ***P*(0,** π/2)



M. Ohtsu (Ed.),

Near-Field Nano/Atom Optics and Technology, Springer 1998

Conclusions

Modern electrical and electronics technologies are used in the space whose size is much smaller than the electromagnetic wavelength.

Similarly, it will be possible to use optical technologies in the space whose size is much smaller than the optical wavelength in the near future.

In this meaning, ***Nano-photonics*** are interesting and important subjects from not only technological view points but also view points of fundamental physics.

Thank you for your attention.

In Jap e technology of ***Nano-photonics*** and are now doing research.

Furthermore, many interesting ideas are proposed by Japanese researchers.

Unfortunately, only a small number of commercial products using ***Nano-photonics*** technology have emerged in the market until now.

I hope that Japan will be able to make large contribution to ***Nano-photonics*** in the future.

Topics of Nano-photonics in Japan 3

APPLIED PHYSICS LETTERS 87, 043112 (2005)

Local density of states mapping of a field-induced quantum dot by near-field photoluminescence microscopy

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(Received 14 February 2005; accepted 23 May 2005; published online 20 July 2005)

We have described near-field photoluminescence microscopy of a field-induced quantum-dot structure based on a Be–δ-doped GaAs–$Al_{1-x}Ga_xAs$ single heterojunction with a surface square mesh gate. The local density of states in the field-induced quantum dot was mapped by measuring the spatial distribution of the near-field photoluminescence intensity, because the photoluminescence spectrum owing to the recombination of holes bound to Be accepters with electrons in an electron gas contains information on the electronic density of states. Experimentally, we observed that the electrons confined in lower energy states spatially localize in a field-induced quantum dot. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1984095]

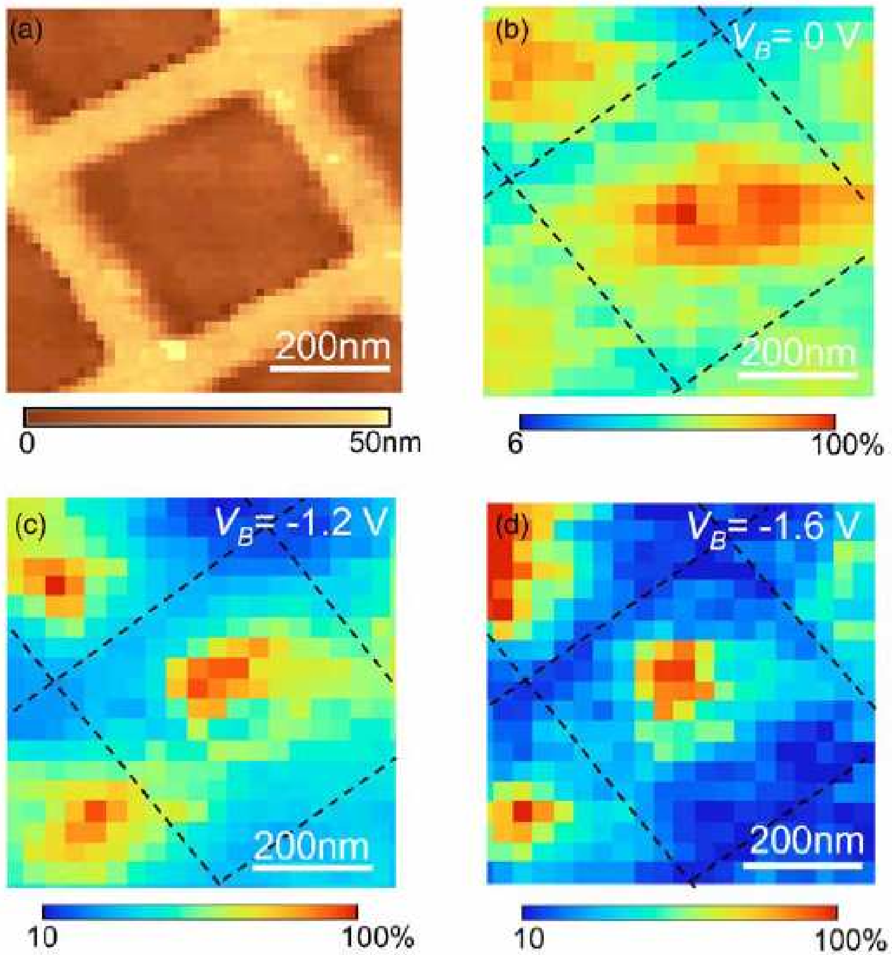
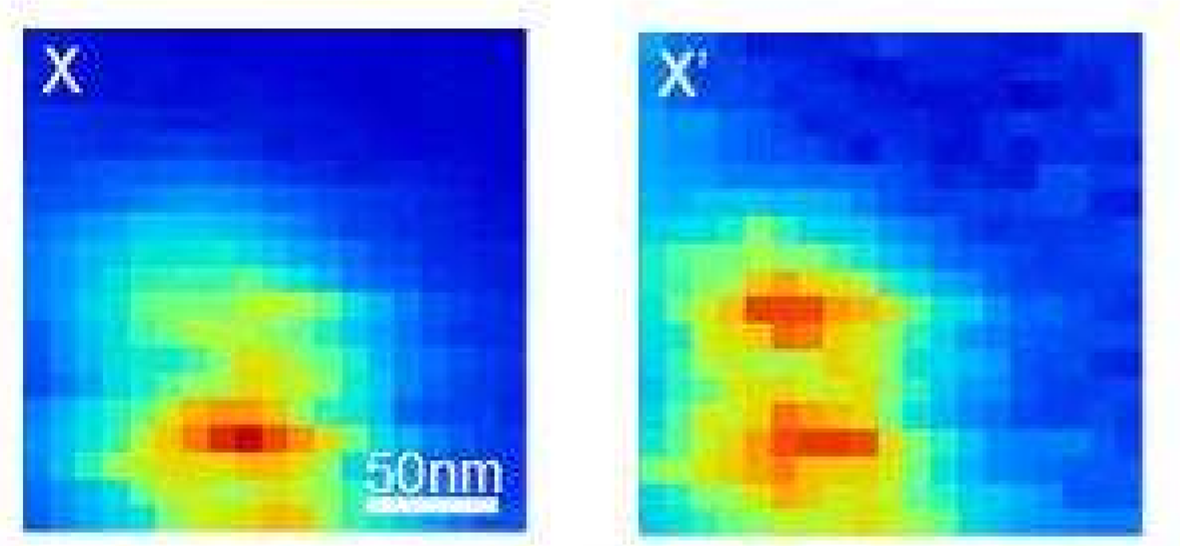


FIG. 2. (Color) (a) Atomic force microscopy image of the gated sample surface. (b)–(d) Near-field PL images at different external bias-voltages (V_B=0, −1.2, and −1.6 V, respectively). These images were monitored at a detection energy of around 1.483 eV at 9 K. The dotted lines in the images correspond to the positions of the surface gate. The scanning area of these images was 775 × 775 nm. (e) Near-field PL image at V_B=−1.6 V, measured for a wide area of 1100 × 1100 nm. The images in (b)–(d) were of the squared dotted area. (f) Cross-sectional PL intensity profile, taken along a diagonal of the mesh gate.



(*a*) (*b*)

Mapping of wave functions inside quantum dots by near-field microscopy. The resolution is 30 nm.

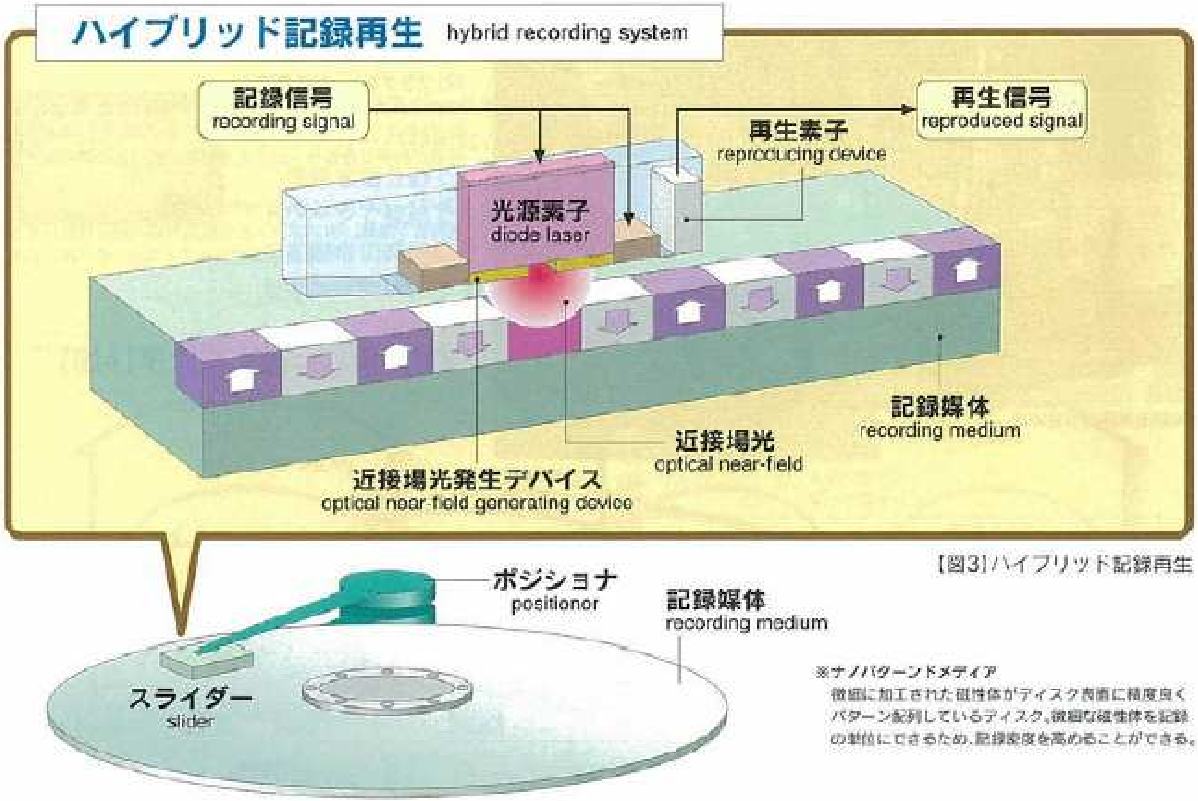
(*a*) Ground state (b) Excited state.

背景・意義

情報通信技術のめざましい進展により、ネットワークがすみずみにまで行き渡り、時間や場所の制約を受けずに、必要とする情報や知識を、誰もが自由に創造、流通、共有できる情報通信環境の実現が望まれています。このような情報通信環境においては、ネットワークに情報通信システム・モバイル端末が多数接続された状態での利用が想定されるため、大量の情報の流通・蓄積に対応した大容量のストレージ技術の発展が不可欠です。このプロジェクトでは、高密度と記録・再生の高速性とを実現する光記録技術の実証を目的としています。

研究開発の内容

平成22年頃には1テラビット/inch^{2}のストレージが必要となることが予想されており、高密度の書きこみをするためには記録セルのサイズを小さくすることが必要です。従来の技術の延長では不可能と考えられている技術を、近接場光技術・ナノパターンドメディア等の先進技術を駆使し、大容量の記録ストレージ実現に取り組んでいます。



【図3】ハイブリッド記録再生

※ナノパターンドメディア
微細に加工された磁性体がディスク表面に精度良くパターン配列しているディスク。微細な磁性体を記録の単位にできるため、記録密度を高めることができる。

今後の展開

平成16年度までには300ギガビット/inch^{2}級を可能とする各種要素技術を開発し、さらに平成18年度までには、1テラビット/inch^{2}級の高密度と記録・再生の高速性を実証します。

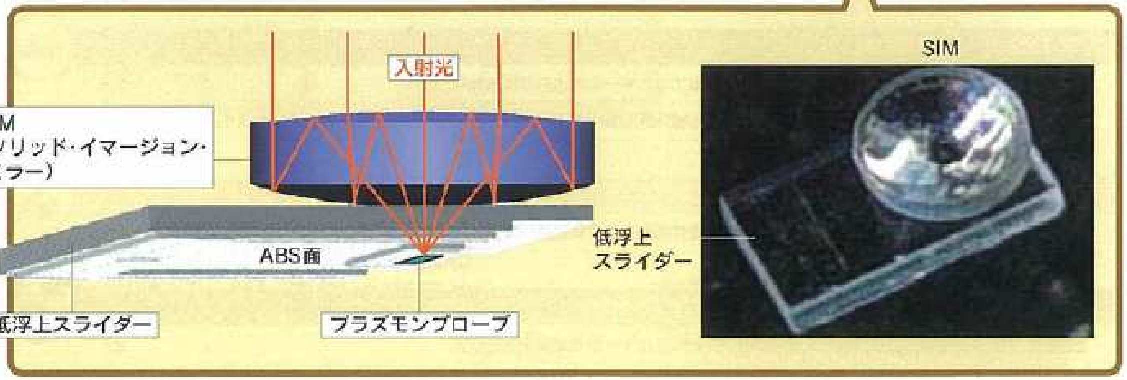
トピックス

プラズモンプローブを使った記録用光デバイスを開発

近年、パソコン等に搭載されているHDD（磁気ディスク）などのストレージの記録容量はどんどん大きくなっています。

高密度に情報を記録するために、ディスク上の小さなセルに記録するには記録光スポットもさらに小さくしなければなりません。高効率集光素子（SIM）※と近接場光発光素子※（プラズモンプローブ）※を組み合わせて低浮上スライダに搭載した記録用光デバイスを世界に先がけて試作しました。

低浮上ヘッド（スライダー）の試作

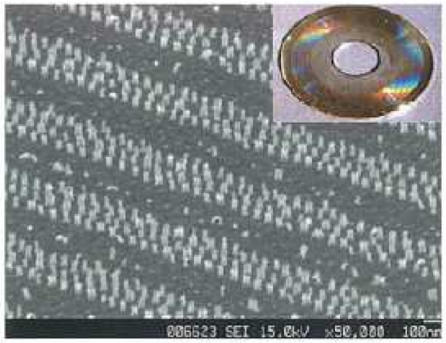


【図1】

※SIM　入射光を近接場のヘッドまで効率良く集光するミラー。

※近接場光
光の波長よりも小さな物質に光を当てたとき、その物質の表面に発生して、遠くへは伝搬していかない光のこと。あたかも物質表面を覆う光の薄い膜のようなもので、膜の厚みは物質の寸法程度なので、当てる光の波長よりも小さくなる。従って、レンズで光を絞るよりも小さな光スポットとなる。

※プラズモンプローブ　近接場光を発光させる素子　[参考]plasmon：電子波



光磁気ハイブリッド材料のドット加工配列に成功

光磁気ハイブリット材料（FePtCu）で、80nmピッチ（ドット径く40nm）のドットのナノ加工配列を自己組織化を用いたプロセスで試作しました。2.5インチ径ディスク全面に円周配列できた世界初の成果として期待されています。

Research Area Virtual Lab in Nanotechnology Area

Creation of Nanodevices and Sys
Phenomena and Functional Princ

Research Supervisor: **Dr. Koji Kajimura**

(Vice President, Japan Society for the Promotion

FY2001

Development of Fundamental Technology for Spin Quantum Dot Memories

Koichiro Inomata

Fellow, National Institute for Material Science

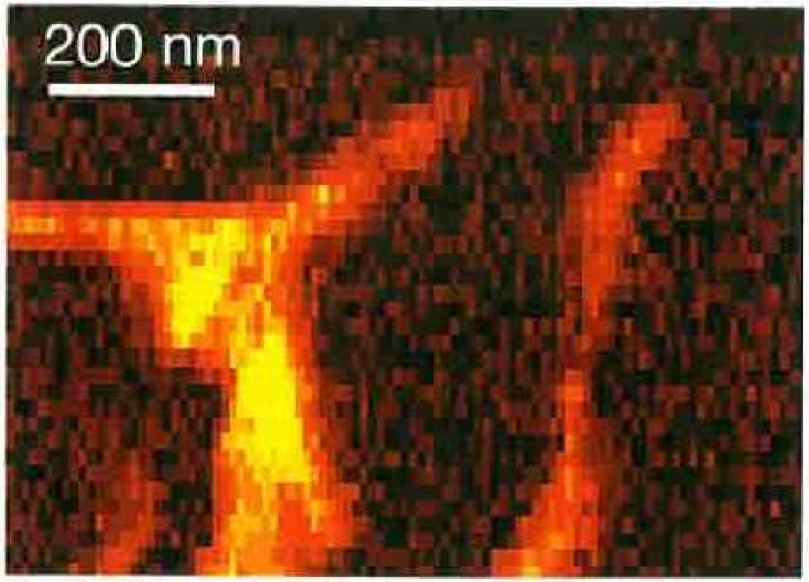
This research aims at the creation of spin quantum dot memories based on a novel concept. The essential part of the research is to demonstrate the spin-dependent Coulomb blockade effect due to single electron tunneling at room temperature in ordered magnetic nano dots, in which the tunneling magnetoresistance can be controlled by applying a voltage. We will develop novel materials or structures to achieve enhanced tunneling magnetoresistance and thus large signal voltage. In addition, the fabrication technology to create two-dimensional array of dots and new memory devices will also be developed. We anticipate, at the end of this research, the creation of terabits non-volatile memories and new spread of spintronic devices.

Nonlinear Nano-Photonics

Satoshi Kawata

Professor, Osaka University

Marvelous novel functions that are not accessible by conventional nanotechnologies are expected if photons are utilized for sensing, manipulating, and processing features at nanoscale. In this research, we will combine the concepts of near-filed optics and non-linear optics, conducting fundamental research on nonlinear nano-photonics and pushing it for practical applications. Of particular interest is applying femtosecond lasers to plasmon field-enhanced technologies for nano-spectroscopy and nano-devices.



An optical image of a DNA network nano-structure obtained by the combination of near-field optics and nonlinear spectroscopy. The distribution of adenine base molecules, one of the DNA bases, is visualized.

Towards plasmonic band gap laser

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(Received 19 April 2004; accepted 7 September 2004)

A two-dimensional periodically corrugated silver surface prohibits the propagation of the surface plasmons in all lateral directions. And band gaps are generated in the dispersion relation, named plasmonic band gaps. At the edge of this band gap, surface plasmons are laterally confined as standing waves. We investigate this phenomenon for lasing action by the use of a dye film deposited on a corrugated silver surface. Fluorescence of the dye was strongly enhanced. Indeed, we obtained an enhancement factor 150 for a methyl-red doped poly (methylmethacrylate) film and 3 for an evaporated 4-dicyanomethylene-2-methyl-6-p-dimethyl-aminostyryl-4H-pyran film. We also discuss the conditions under which lasing action may occur.

1. ナノプラズモニクス（岡本，H'Dhili[*1]，Feng[*1]，Simonen[*2]，奈良岡[*1]，井田[*3]）

プラズモニック結晶は金属表面に二次元表面レリーフ格子を刻むことによって光子を三次元的に閉じこめる構造である。プラズモニック結晶における輻射特性をフーリエモーダル法を用いて解析した。その結果，格子の形状をデザインすることにより，輻射特性を制御できることが分かった。また，金属として薄膜を用いることで両界面の表面プラズモンの相互作用により，吸収損失が低減できることが分かった。さらに，実際に色素薄膜を堆積したプラズモニック結晶を作製し，その光学特性を測定した。陰極としてプラズモニック結晶を用いることで，高効率の上面発光が得られる有機 EL 素子を開発した。

1. ナノプラズモニクス（岡本，H'Dhili[*1]，Feng[*1]，柳沢[*2]）

表面プラズモン共鳴と二次元フォトニッククリスタルを組み合わせたプラズモニック結晶の吸収スペクトルおよびその上に堆積した色素膜からの蛍光スペクトルを観測し，その光学特性の解析を行った。また，プラズモニック結晶を用いたレーザー発振の可能性について検討した。プラズモニック結晶を電極として用いた有機 EL 素子を作製し，その発光スペクトルの角度依存性から，素子の光学特性を解析した。本素子の外部発光効率は，プラズモニック結晶を用いない場合と比較して 10 倍向上した。

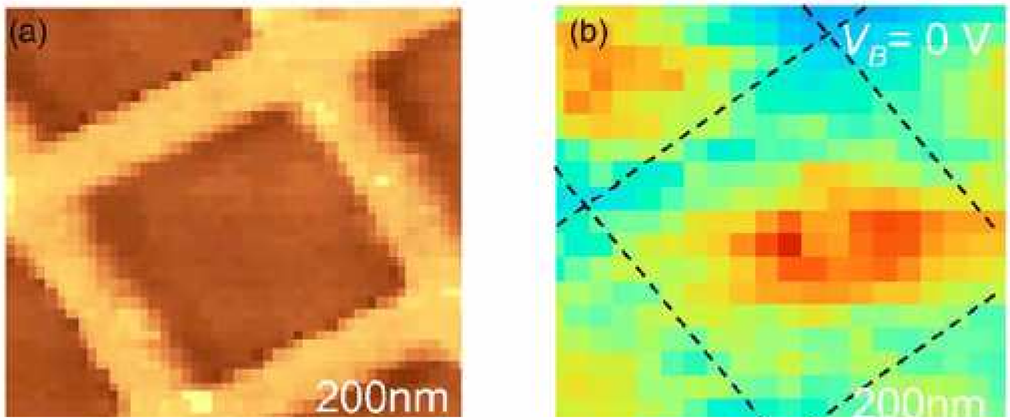
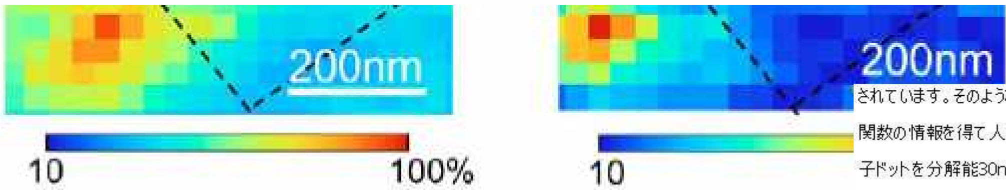
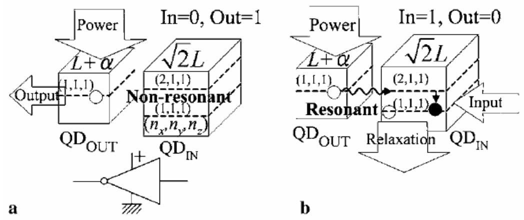


FIG. 2. (Color) (a) Atomic force microscopy image of the gated sample surface. (b)–(d) Near-field PL images at different external bias-voltages (V_B=0, −1.2, and −1.6 V, respectively). These images were monitored at a detection energy of around 1.483 eV at 9 K. The dotted lines in the images correspond to the positions of the surface gate. The scanning area of these images was 775×775 nm. (e) Near-field PL image at V_B=−1.6 V, measured for a wide area of 1100×1100 nm. The images in (b)–(d) were of the squared dotted area. (f) Cross-sectional PL intensity profile, taken along a diagonal of the mesh gate.



されています。そのようなデバイスを実現するためには、量子ドット内部の情報、つまり波動関数の情報を得て人為的に操作してやる必要があります。下の図は大きさ200nmの量子ドットを分解能30nmの近接場光学顕微鏡(NSOM)でスキャンしたものです。Xは量子ドットにおける励起子基底状態、X'は第一励起状態(X')の波動関数の振幅を表しています。



Appl. Phys. B 84, 243–246 (2006)

DOI: 10.1007/s00340-006-2234-x

Applied Physics B
Lasers and Optics

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Demonstration of nanophotonic NOT gate using near-field optically coupled quantum dots

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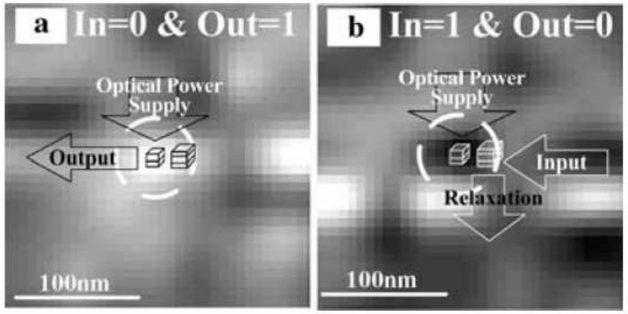
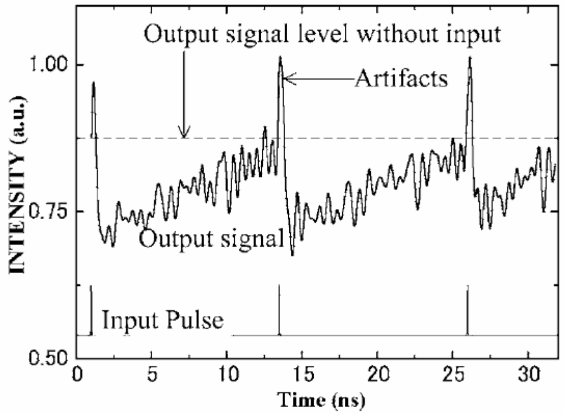


FIGURE 2 The spatial distribution of the output signal from a nanophotonic NOT gate measured using a near-field microscope at Input = 0 (**a**) and Input = 1 (**b**)



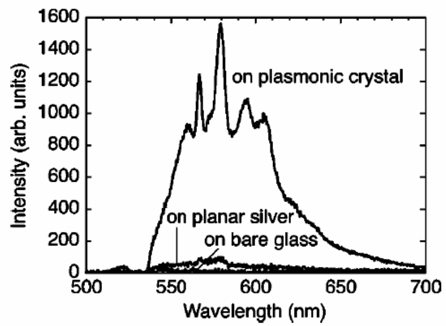


FIG. 3. Fluorescence spectra of a methyl-red doped PMMA film deposited on a bare glass substrate, on a planar silver surface, and on a 507 nm pitch plasmonic crystal.