Photonic polymer research based on strategic promotion of innovative research and development supported by Japan Science and Technology Agency

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ABSTRACT

Japan Science and Technology Agency (JST) have launched a new program called strategic promotion of innovative research and development (S-Innovation). Projects chosen for the S-Innovation program are selected from among the research output of JST's strategic and basic research programs, such as CREST, ERATO, Sakigake and PREST, which aim to create innovative new technologies, lead to the advancement of science and technology and the emergence of new industries. S-Innovation covers R&D themes from the aforementioned programs and is based on the seamless, long-term pursuit of R&D toward the practical application of novel technologies. It is envisaged that the innovation resulting from such technologies will form the foundations of future industries. Currently the program consists of four projects in which photonics polymers are included. The photonic polymer research consists of five topics such as development of fast organic photorefractive polymers for advanced optical communication technology, development of new device technology based on nano-ordered structures of polymers, development of three-dimensional vector wave memory, optical interconnect device technology using high performance photonic polymers and development of quantum photonic technologies with polymer optical nano-fibers. Each topic is funded approximately $1.0 M/year for ten years. The objectives and unique features of S-innovation and the highlights of each topic are described.

1. INTRODUCTION

Japan Science and Technology Agency (JST) is one of the biggest funding agencies in Japan and promote science and technology which will create new values and lead to the future, in order to advance the national welfare and prosperity. JST has three visions. One is to help generate innovation based on science and technology, through the development of networks between academia and industry. The second is to support development and activities of personnel who are to advance and deploy science and technology, while enhancing science communication between the public and S&T related professionals. The last is to advance science and technology for sustainable development, while playing a role in Japan's leadership in the S&T field in the face of global society.

In order to realize the visions JST is involved in the various activities including promotion and support of international research cooperation. Among them the biggest activity is the creating advanced technology promoting targeted basic research to achieve strategic objectives set by the government. The basic research program is consisted with three categories. One is called CREST which is a team-oriented research that generates seeds of innovation with a large impact. The optimal research team is organized to implement research. The research supervisor takes leadership in managing research as the leader of the research area. The other is called PREST (Sakigake) which is an individual-oriented research that nurtures seeds of future innovation. Researchers with flexible mind-set and determination to take on new

Organic Photonic Materials and Devices XIII, edited by Robert L. Nelson, François Kajzar, Toshikuni Kaino, Yasuhiro Koike,
Proc. of SPIE Vol. 7935, 79350J · © 2011 SPIE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.881261

challenges are gathered together to conduct research under the research supervisor. The third one is called ERATO which aims to create new research areas that will be the headwaters of future S&T, by aggressively generating S&T seeds that are unique to Japan. It is characterized by diverse personnel and independent research system. The strategic promotion of innovative research and development (S-Innovation) started from the end of 2009, and the fields of the research areas chosen for the S-Innovation program are selected from among the research outputs such as CREST, ERATO, Sakigake and PREST, which aim to create innovative new technologies, lead to the advancement of science and technology and the emergency of new industries. These basic research programs (BRPs) have produced successful "seeds" that respond to the needs of society and industry. Focusing on "seeds" from BRPs, "S-innovation" aims to bring up these "seeds" to "key technologies" for new industries in order to trigger innovation and provide benefits from innovation to our society. After successful "seeds" are investigated to set up promising R&D theme, JST designates program officer (PO) for each theme. (Top-down) Each PO shows "R&D concept" including expecting topics, output images etc. "Top-down" enables JST to more actively focus on "seeds" from BRPs, also enable each PO to strongly control R&D promotion with R&D concept.

The unique feature of "S-innovation" is long-term seamless funding up to 10-years R&D period. The term is divided into three stages. Stage 1 is applied basic research. Stage 2 is component technology R&D. Stage 3 is application development. R&D term can engage in long-term R&D activity which is enable to bring up "seeds" to "technology" and also to "application" with R&D budget support. The average funding size for one team is about $1.0M per year. But the flexible distribution to each team can be done by PO. In order to make easy to transfer the developed technology from academia to industry, collaboration of industry and academia and information sharing between them are promoted by PO. JST expects "Open Innovation" make R&D activities more efficient to stimulate innovation. The expenditure of JST in 2010FY is shown in Figure1.The program overview is shown in Figure2.

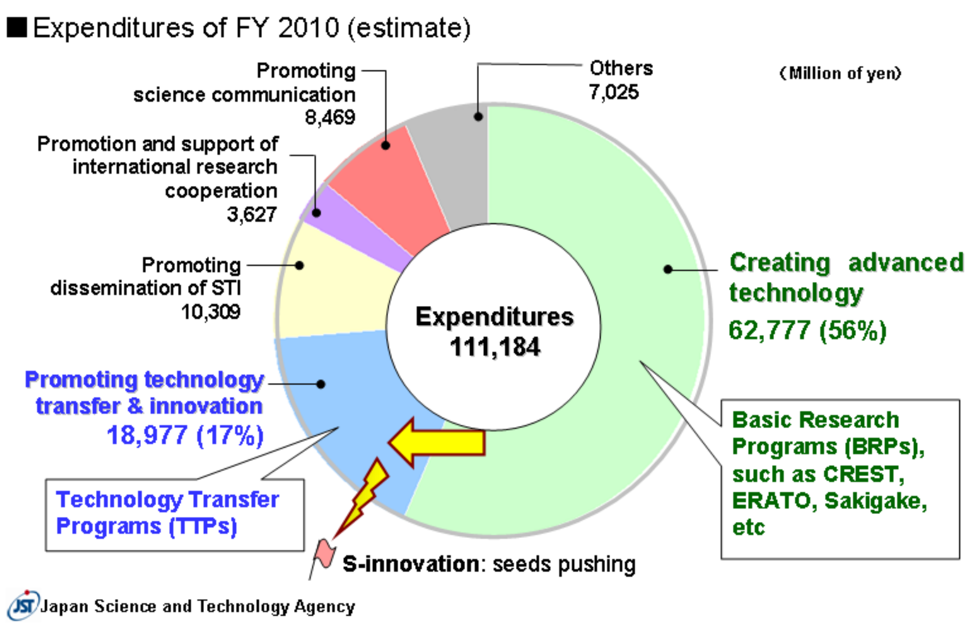

Figure1. Expenditures of FY 2010 (estimate)

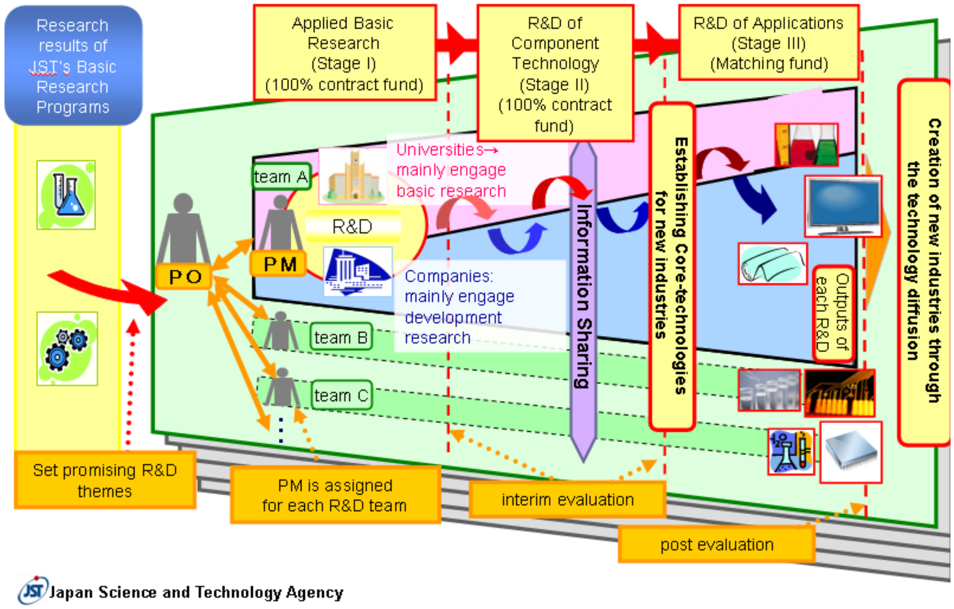

Figure 2.Program Overview

2. TOPICS IN PHOTONICS POLYMER

2.1 Development of fast organic photorefractive polymer for advanced optical communication technology

P.M., Professor Naoto Tsutsumi of Kyoto Institute of Technology

The main objective of the project is the development of fast and high diffraction photorefractive polymers for real-time holographic 3D imaging and displays.

In Table 1, summaries of the basic photorefractive performances to be achieved at each stage (present and forward stages) in his project and current values achieved are listed. At the present stage the team has already succeeded high diffraction efficiency up to 70 %, optical gain up to 100 cm^{-1} and response speed of 100 s^{-1}. Diffraction efficiency is plotted as a function of applied electric field in Figure 3. High diffraction efficiency of 70 % was measured at moderate applied electric field of 45 V/μm.

Table 1. Objectives and Achievement

	Stage I, II (2009～2013)	Stage III (2014 ～)	Present stage (2010 12/7)	Evaluation
Diffraction eff. (%)	20 %	50 %	70%	Excellent
Optical gain (cm^{-1})	100 cm^{-1}	200 cm^{-1}	100 cm^{-1}	Good
Response time (ms)	10 ms	1 ms	5 – 10 ms	Good
Response speed (s^{-1})	100 s^{-1}	1000 s^{-1}	100 – 200 s^{-1}	Good
Video rate (s^{-1})	33 s^{-1}	1000 s^{-1}		

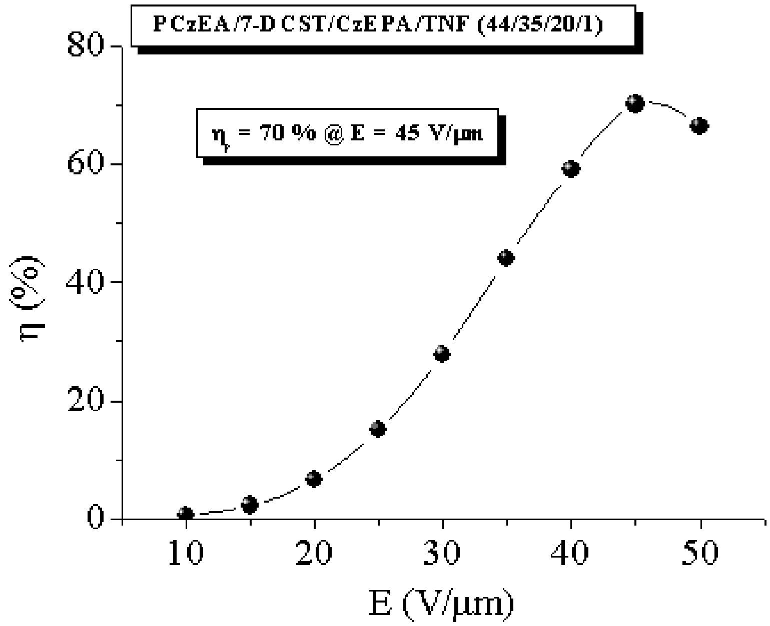

Figure3. High diffraction efficiency for p-polarized beam

The team has also developed new measurements technique to characterize photorefractive quantities of electro-optic coefficients, carrier mobility, and mean path length of photo carriers etc. New type of photorefractive liquid crystalline materials has been developed for fast response speed.

Figure 4 shows the picture images of daphnia in the object cell on a screen. At left picture, edge enhancement with long time afterimage is observed with applying at 3.5 kV. At right picture, more edge enhancement with short time afterimage is observed with applying at 4.5 kV. They demonstrate the real-time novelty filtering with more clear edge enhancement with shorter time afterimage on higher applying electric field.

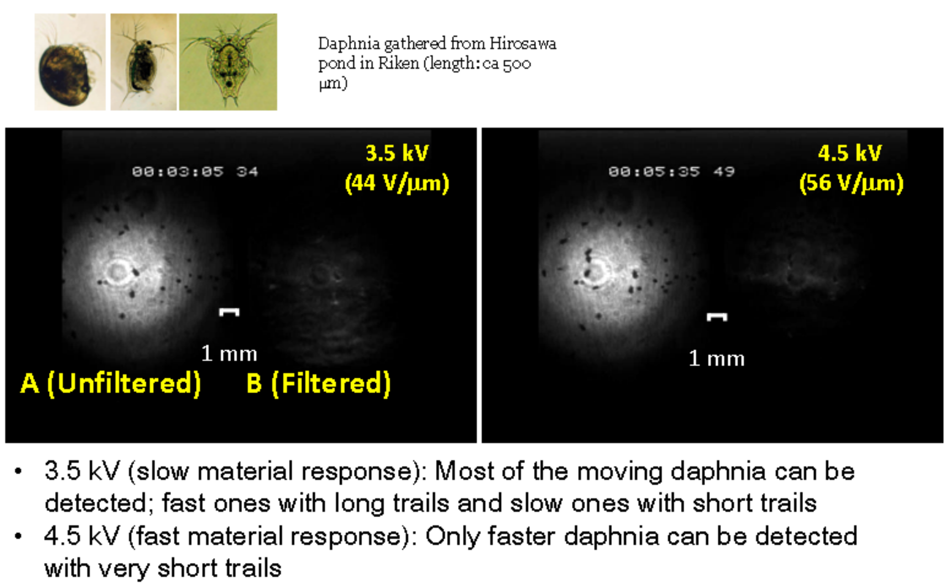

Figure4. Detected Moving Daphnia

2.2 Development of new device technology based on the nano-ordered structures of polymers

P.M., Professor Junji Watanabe of Tokyo Institute of Technology

His team has been developing new liquid crystal polymers to control nano-ordered structure as shown in Figure5.They succeeded to reduce threshold energy for lasing less than 1/20 by mixing laser dye such as DCM in cholesteric liquird crystal (CLC) as shown in Figure 6. This remarkable improvement is due to the formation of better cavity to constrain incident light.

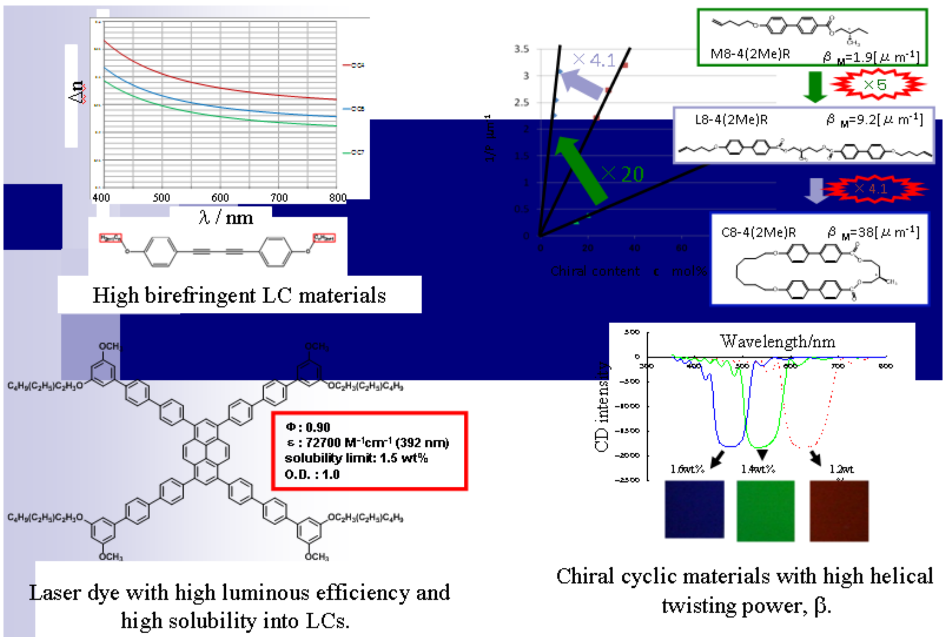

Figure 5. Preparation of materials with high optical performances.

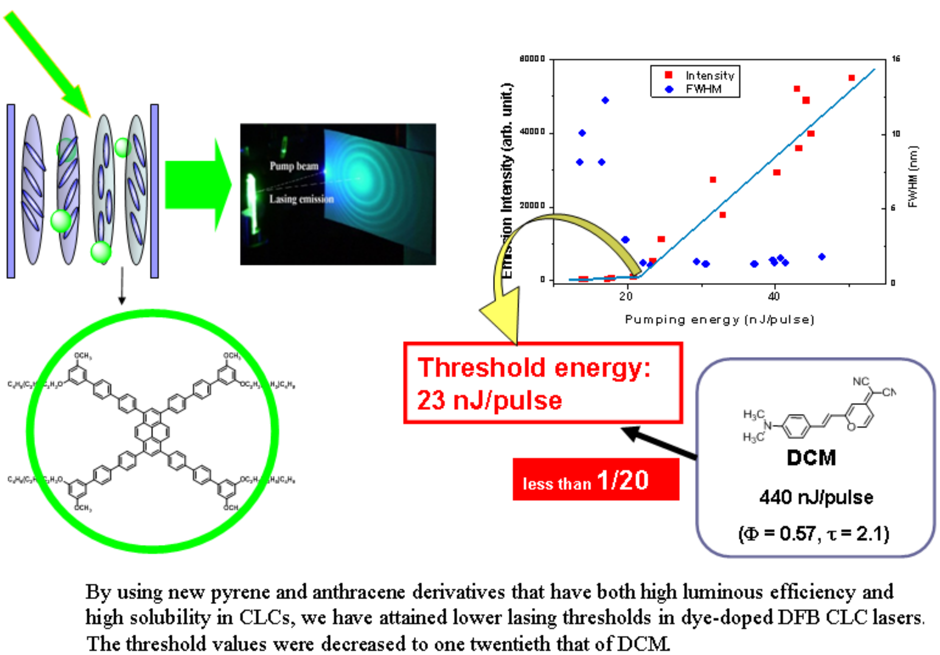

Figure6. Laser dyes to realize low threshold in dye-doped cholesteric liquid crystal (CLC) lasers.

2.3 Development of three dimensional vector wave memory

P.M., Professor Toyohiko Yatagai of Utsunomiya University

An optical recording technique, called retardagraphy, can record a retardance pattern of a birefringent object on a polarization-sensitive medium made of azobenzene copolymer. In holography, a recording laser beam must be split into signal and reference parts. In contrast, it is not necessary for the retardagrapy to split the recording laser beam. This feature simplifies the optical system. The multi-valued phase pattern recorded on the polarization-sensitive medium can be reconstructed by measuring retardation between two polarization components. The optical recording and reconstructing methods of binary and multi-valued phase patterns are demonstrated by retardagraphy.

His team has already developed volume recording media, which can perform angular multiplex recording. Bragg diffraction with polarization dependence has been observed in the polarization gratings. Furthermore, 10 times recording of the orthogonal circular polarization pattern was succeeded. This means that polarization-sensitive media are applicable to (volume) polarization-sensitive digital optical elements and optical data storage with polarization as shown Figure 7. Currently 10T/byte optical memory based on polarization sensitive polymer is under developing.

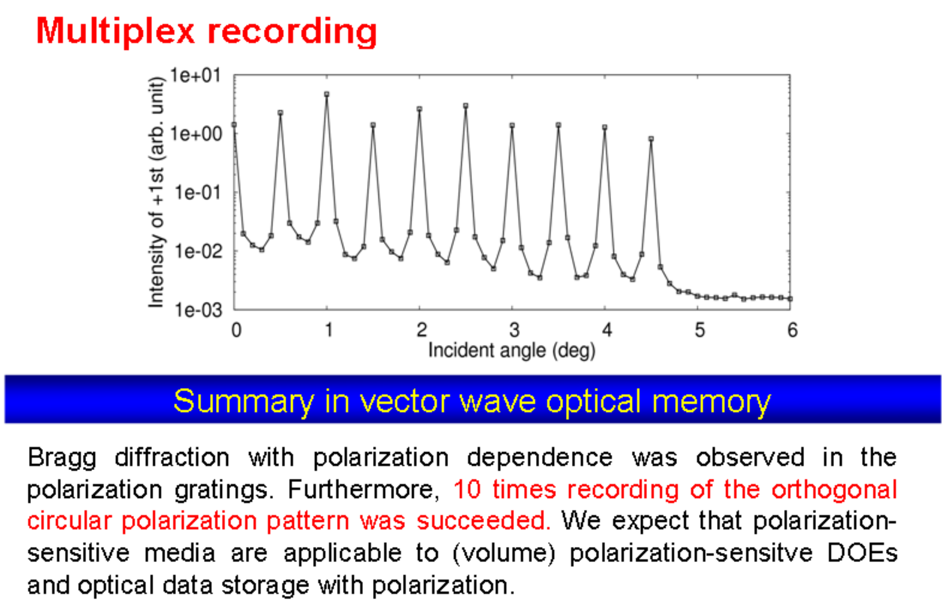

Figure 7. Multiplex recording in polarization-sensitive photopolymer.

2.4 Optical interconnect device technology using high performance photonics polymers

P.M., Associate Professor Okihiro Sugihara of Tohoku University.

In order to realize the integrated optical circuit, we have 4 issues that should be developed, such as 1) high performance electrooptic polymers, 2) high index hybrid materials, 3) passive and electro optic waveguide devices, and 4) low loss optical connection and integration. Using variety of fundamental technologies that we possess now we combine them and fabricate an integrated module. His team has succeeded to increase refractive index to 1,939 at 594nm by mixing TiO_2 nanoparticles with UV-curable acryl ate resin (#6205, NTT-AT Corp.) with refractive index about 1.7. The transmittance of the TiO_2 nano composite is more than 95% of incident light is the region from 500nm to 1600nm. Moreover, a waveguide grating was successfully fabricated based-on light-induced self-written (LISW) waveguide technique. Grating was fabricated by two-beam interference method using a phase mask after formation of LISW waveguide. A light from an infrared LED and an ASE source was launched to the LISW waveguide through a single-mode fiber, and a reflected signal was detected by a spectrum analyzer. Fig.8 shows the typical result. A strong reflection at 1559nm was observed for a waveguide with grating. On the other hand, no remarkable wavelength filtering was observed for a waveguide without grating. These results suggests that 3D LISW waveguide grating was successfully fabricated., and such device can be installed in polymer integrated optical modules.

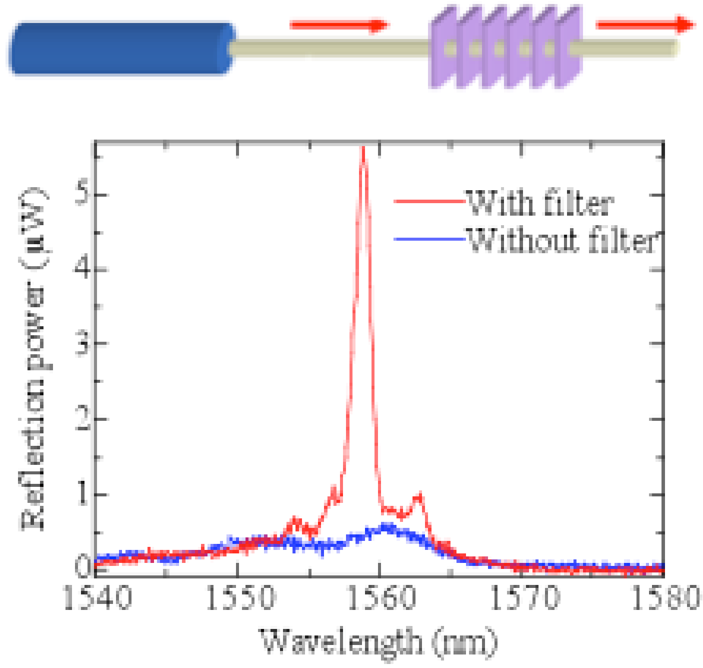

Figure 8. Waveguide grating fabricated by LISW technique.

2.5 Development of quantum photonic technologies with polymer optical nanofibers

P.M., Professor Kozo Hakuta of the University of Electro-Communications.

In quantum information systems, information's are carried not by the coherent light but by the flow of single photons and/or twin photons. Therefore, one of the key issues of the method is to establish an efficient and deterministic photon-generation technology which is readily applicable to the optical fiber communication line. Mission of the project is on this issue. We develop an efficient and deterministic photon-generation method, which is applicable to the optical fiber communication line. Specialty of the project is to combine optical nanofiber technologies to photonic polymer technologies. We develop nano-fabrication method for the polymer optical nanofibers so that single photons and twin photons are generated in the fiber propagation mode efficiently and deterministically.

Thus, this project develops a key technology for quantum information system, especially on photon generation method. Technically, the method works at room temperature and is readily incorporated to the fiber communication system. Strategy of the project is to combine optical nanofiber technologies with photonic polymer technologies. We develop nano-fabrication method for the polymer optical nanofibers so that single photons and twin photons are generated in the fiber propagation mode efficiently and deterministically. As for photon emitters, we use quantum dots. Key point to realize efficient and deterministic photon generation is the following two issues. One is the nanofiber-cavity, that is to fabricate cavity structure on the nanofiber. The other is core doping of single quantum dot, that is realized via polymer coating of the nanofiber. Once the technology has been established, it can be extended to quantum memories by using 3-level quantum emitters, like nano-diamonds. Figure 9. shows the recent results on one photon generation and nanofiber grating.

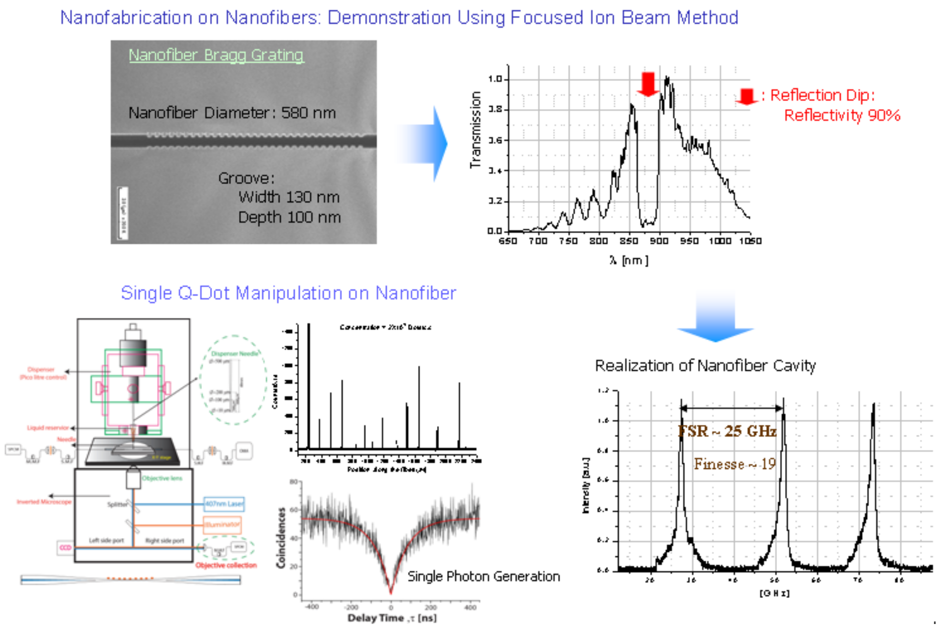

Figure 9. Present Status