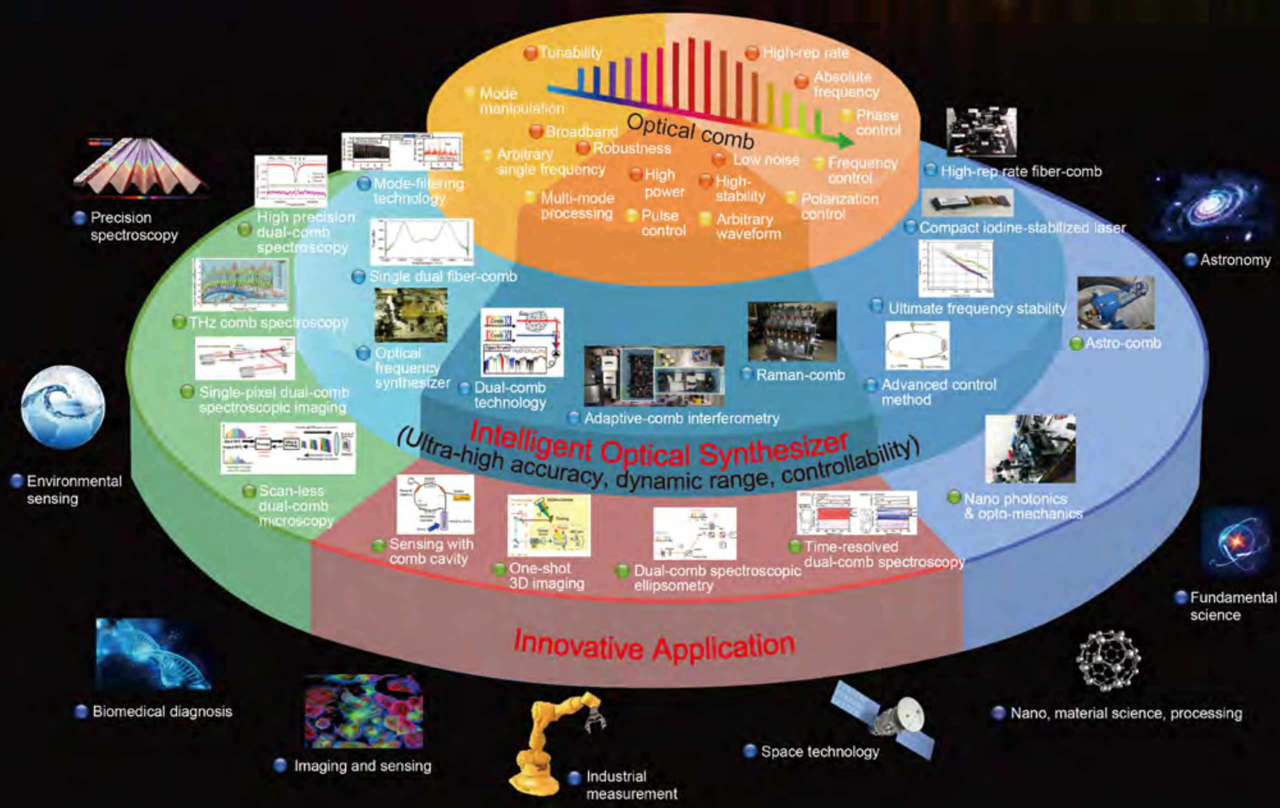
JST ERATO

MINOSHIMA Intelligent Optical Synthesizer Project

Developing a fundamental and revolutionary light source "intelligent optical synthesizer" to explore innovative application fields



Japan Science and Technology Agency

Project Outline

Research Area : Intelligent Optical Synthesizer

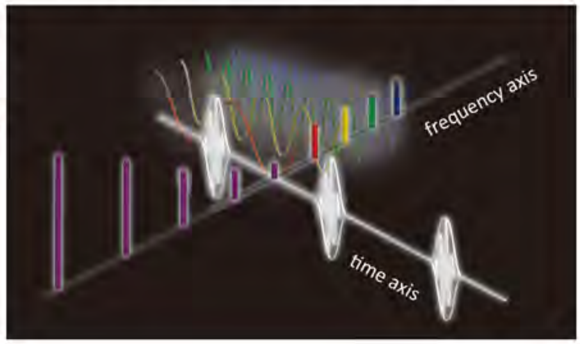
Research Period : October 2013 to March 2019

Research Director : Kaoru Minoshima Professor, Graduate School of Informatics and Engineering, The University of Electro-Communications

By exploiting the phase and frequency information, light can be used to perform the direct transfer of information with an extremely wide dynamic range. In this way, light waves would become a truly intelligent fundamental entity. Thus, light may become a key quantity that delivers benefits on a daily basis to society and various industries related to medicine, the environment, energy, safety and security, materials, and manufacturing.

It is within this context that this research project is working toward developing an "optical comb," (an advanced light source whose spectrum has discrete peaks at regular intervals on the frequency axis in a precise comb shape) into a fundamental and revolutionary "intelligent optical synthesizer" by combining electronics and optical technologies. We aim to develop an intelligent light source for which all the light wave parameters including in the domain of time, space, frequency, phase, intensity, and polarization can be freely controlled and to use this light source to uncover and explore novel application fields.

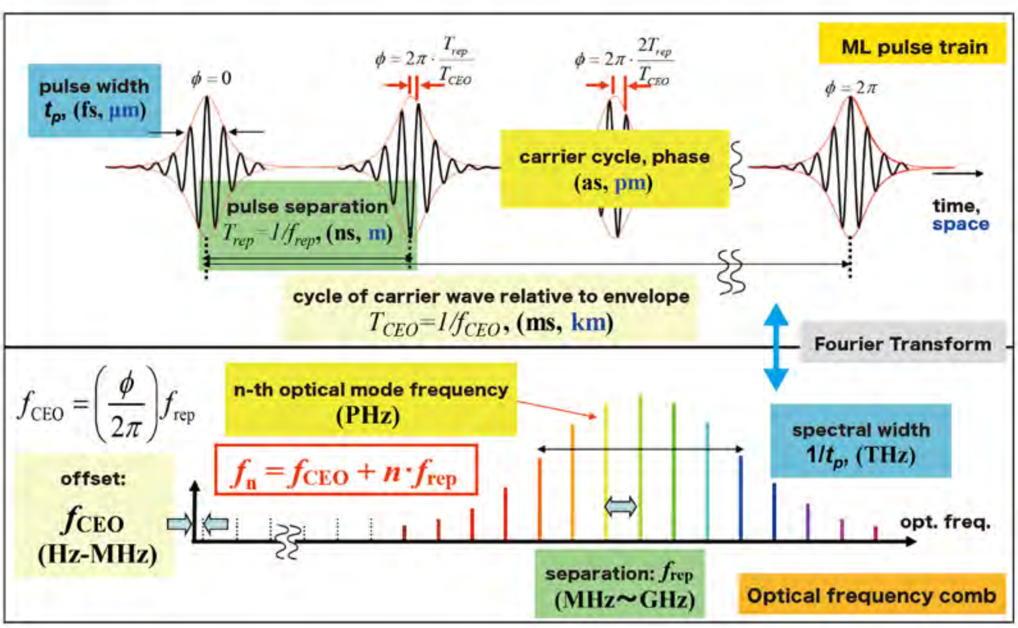
http://www.jst.go.jp/erato/minoshima/en/index_e.html



What is Optical Comb?

Fine resolution of the spectrum (colors) of the ultra-short pulse laser (mode-locked laser) reveals multiple equally spaced optical frequency modes. This is called an optical comb because it shaped like comb teeth (Optical comb is also called optical frequency comb).

Optical comb can be used as a precise measure of time, space and frequency. Like a ruler with graduations of different sizes, optical comb also has references of different ranges. For example, multiple references for frequency axis are optical mode frequency (sub PHz), spectral width (THz), separation (GHz), and offset frequency (MHz or less). Those have precise mutual relations, and by using them as precise references of a broad range, ultra-precision measurements and control can be realized.



Project Organization

Research Director Kaoru Minoshima

Headquarters

Collaborative Research

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Kaoru Minoshima

Intelligent time and space domain technology group
The University of Electro-Communications

Leader
Hajime Inaba

Extreme frequency metrology group
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Takeshi Yasui

Terahertz and broadband spectrum manipulation group
Tokushima University

Contract Research

Professor
Hiroyuki Sasada

Keio University

Professor
Feng-Lei Hong

Yokohama National University

Associate Professor
Hideyuki Izumiura

National Astronomical Observatory of Japan

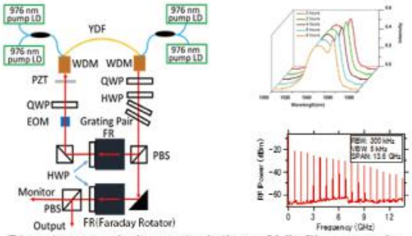
Director
Satoshi Hatano

NEOARK Corporation

Research Contents: Development of Intelligent Optical Synthesizer

High-rep Rate Fiber-comb

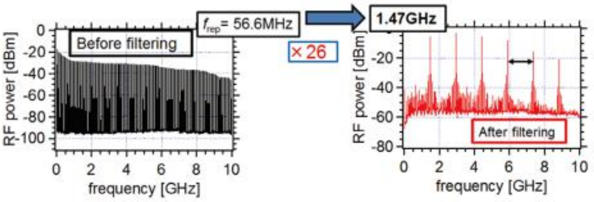
We are working on advancing the Yb-doped fiber-comb with repetition frequency of 750 MHz, and to achieve high quality and high power necessary for applications.



Structure and characteristics of Yb fiber-comb

Mode-filtering Technology

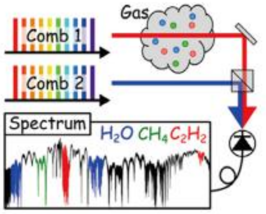
We achieved a significant improvement in the sensitivity of the dual-comb spectroscopy by developing a mode-filtering system using Fabry-Perot cavities.



RF spectrum of comb output before and after filtering

Dual-comb Technology

We have developed several systems for dual-comb technology with broadband, high resolution and high accuracy and fundamental researches are in progress for various applications including gas analysis.



Schematic diagram of gas analysis using dual-comb

Adaptive-comb Interferometry

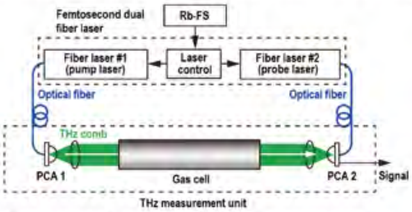
We have developed the air refractive index selfcorrection technology to measure distance using a two-color interferometer and succeeded in obtaining correction uncertainty that surpassed the conventional empirical equations.

Photograph of two color interferometer experiment setup

Research Contents: Exploration of Innovative Applications

Terahertz Comb Spectroscopy

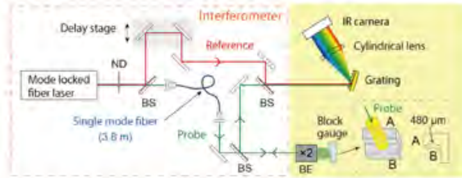
We are developing the terahertz comb spectroscopy system that has both high spectroscopic and real time capabilities, and are working on application research such as gas analysis in the terahertz region.



Setup of terahertz comb spectroscopy system

One-shot 3D Imaging

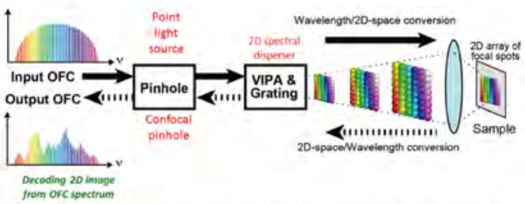
We developed a new imaging method to instantaneously obtain the shape information by acquiring distance information of multiple points at the same time by measuring the spectral interference of chirped ultrashort pulse train of optical comb with IR camera. We are promoting the research to improve the performance and to broaden applications.



Scheme of 3D imaging experimental system

Scan-less Dual-comb Microscopy

We developed an optical comb based microscope using 2D spectral disperser (VIPA and diffraction grating), and proved that 2D confocal image can be obtained without scanning.



Conversion of 2D information to wavelength of optical comb

Time-resolved & Coherent Spectroscopy

New methods such as ultrafast time-resolved measurements and coherent modulation spectroscopy were developed with extension of dual-comb spectroscopy and opened up new application areas such as evaluation of solid state properties.

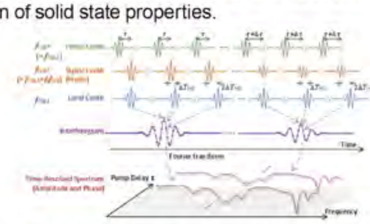
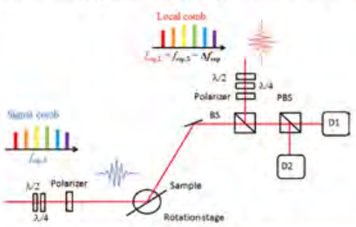


Diagram of the time-resolved dual-comb spectroscopy principle

Dual-comb Spectroscopic Ellipsometry

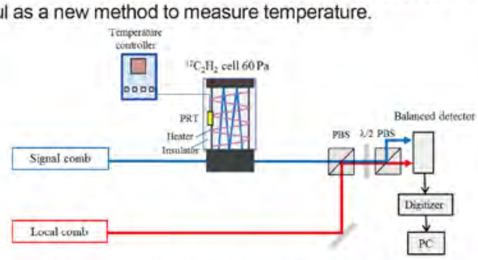
By applying dual-comb spectroscopy method to ellipsometry, we succeeded in measuring the ellipso-parameters (Δ, Ψ) with high wavelength resolution in physical property measurement of thin films.



Dual-comb spectroscopic ellipsometry experiment setup

Optical Comb Thermometer

We developed the temperature measurement technology for gas molecules using dual-comb spectroscopy and proved that this is useful as a new method to measure temperature.



Experimental system of dual-comb thermometer

Astro-comb

We developed the optical comb system (astro-comb) suitable for astronomy applications. This system has been installed in the Okayama Astrophysical Observatory, National Astronomical Observatory of Japan for observation and evaluation.

188 cm astronomical telescope equiped with astro-comb

Nano Opto-mechanics

By using the high accuracy repetition pulse frequency and spectrum of optical comb, we are aiming to create nano opto-mechanics technology that can accurately measure the mechanical response of nanostructures.

Nanostructure vibration measurement system using optical comb as a light source

Achievements

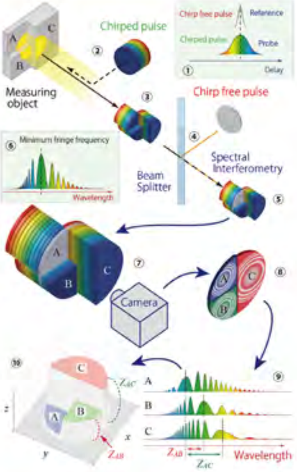
New high-speed 3D imaging method using optical comb has been successfully demonstrated
~ Instantaneous 3D measurement realizing wide range and high accuracy simultaneously ~

The research group at The University of Electro-Communications has developed the instantaneous imaging method applicable to high accuracy and wide range measurements, which obtains the distance information to the measurement target by converting into color (frequency) information.

The ultrashort pulse train emitted repeatedly from the optical comb generated using fiber laser is divided into two parts. One part consists of optical pulse (chirped pulse) that changes color (frequency) regularly with time and is irradiated on the object to be measured, and the light that is reflected is made to interfere with the optical pulse (chirp-free pulse) of the other part that does not change color (frequency). The pattern of interference is recorded using a camera, and distance information can be extracted by a simple analysis. By measuring the step profile of an object (block gauge) with known step difference, we have proved in principle that a 3D shape can be instantaneously obtained by using this method. The distinctive feature of this method is to measure large objects without loosing the accuracy by using a pulse train emitted repeatedly with precise intervals from the optical comb.

This method can be expected to have various applications such as high-speed 3D shape measurement of objects that are extremely small, have large step difference, or with a high length to width ratio, and instantaneous imaging of single-shot phenomena.

(Press release June 2017)



Paper: T. Kato, M. Uchida, and K. Minoshima: Scientific Reports **7**, 3670 (2017)

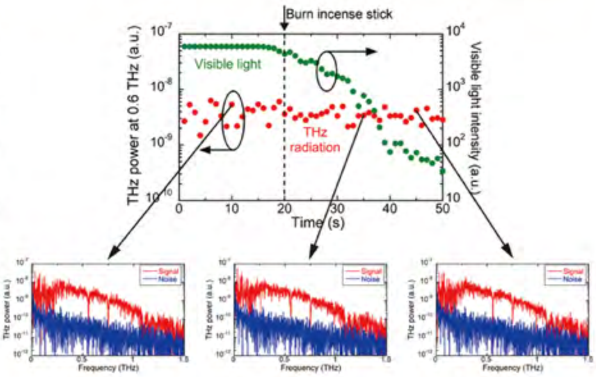
Real Time Analysis of the Concentration of Gas Mixed with Smoke using Terahertz Wave (Terahertz Comb) with Comb Tooth Shape

The international collaboration research group of Tokushima University and Université du Littoral Côte d'Opale (University of the Littoral Opal Coast, France) has succeeded in developing a technology that analyzes the concentration of gas mixed with smoke in real time.

A terahertz wave (terahertz comb) shaped like a comb tooth based on the rubidium frequency standard with highly accurate frequency intervals was generated, and by accurate and high-speed scanning using a method called asynchronous optical sampling terahertz time-domain spectroscopy, both high spectroscopic performance (high-accuracy, high-resolution and broadband) and real time capability (per second measurement rate) were achieved for the analysis of gas mixed with aerosol. In addition, acetonitrile gas concentration that changes in real-time in an environment filled with smoke could be analyzed at the detection limit of 200 ppm by applying an analytical model that considered hundreds of rotational absorption spectra present in the broadband terahertz spectrum.

This method of analyzing gases mixed with aerosol is expected to be useful in improving the efficiency of combustion processes, preventing secondary damage at fire sites, and analyzing air pollution.

(Press release June 2016)



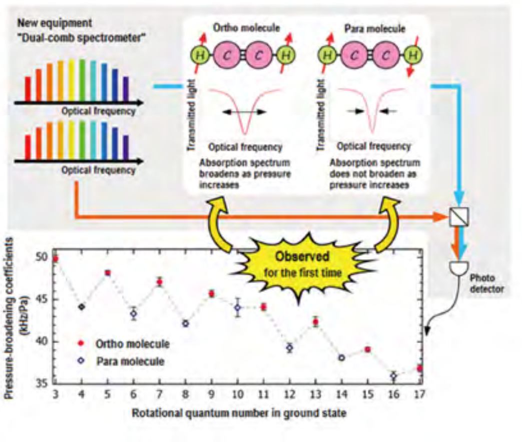
Paper: Y. Hsieh, S. Nakamura, D. Abdelsalam, T. Minamikawa, Y. Mizutani, H. Yamamoto, T. Iwata, F. Hindle, and T. Yasui: Scientific Reports **6**, 28114 (2016)

Discovery of the Nuclear Spin Dependence in Molecular Collision Process
- Achievement of dual-comb spectrometer -

The research group at Keio University in collaboration with the research group at National Institute of Advanced Industrial Science and Technology and the research group at Yokohama National University discovered that the molecular collision process is dependent on nuclear spin.

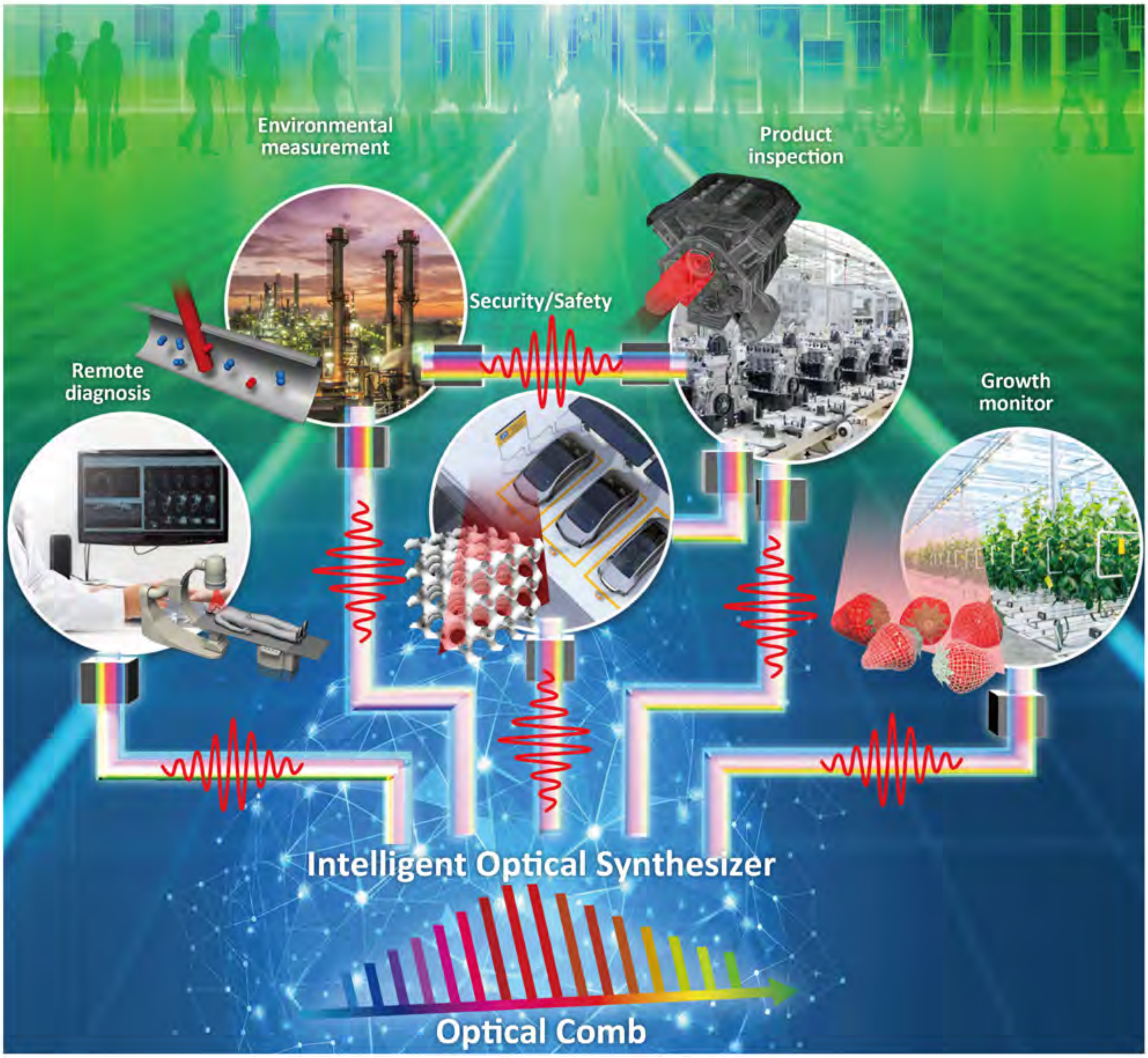
Nuclear spin of atoms that constitute molecule was considered not to have any impact on the collision process between molecules. After thoroughly investigating many absorption spectral lines of acetylene molecule (C_2H_2) under varying pressures using high performance dual-comb spectroscopy, spectral line width changes were discovered for the first time in the world depending on whether the nuclear spin of 2 hydrogen (H) atom nuclei was parallel or anti-parallel to each other. This result will have an impact ranging from the fundamental theory of molecular collision to models that predict environment on the earth and celestial bodies using the atmospheric spectrum.

(Press release September 2016)



Paper: K. Iwakuni, S. Okubo, K. Yamada, H. Inaba, A. Onae, F. Hong, and H. Sasada: Phys. Rev. Lett. **117**, 143902 (2016)

The world led by the intelligent optical synthesizer



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MINOSHIMA Intelligent Optical Synthesizer Project

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