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R&D in Antimony-based Quantum Dot Surface-Emitting Lasers
— Toward Breakthrough Uses of New Materials in

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1. Research Background

With the advance of the information-communication society, it is easy to predict that the volume of communications will increase. This will inevitably be accompanied by a growing number of communication-network devices and a corresponding demand for improved device performance. When developing new devices, it is thus important to focus on increasing speed while reducing power consumption, size, and price.

The Optoelectronics Group within the NICT (National Institute of Information and Communications Technology) is conducting basic research in optical devices to be used in optical communications in the near future. One of our research subjects consists of what is referred to as “quantum-dot laser” technology. As shown in Figure 1, quantum-dot technology is a type of nanotechnology that enables artificial equalization of the energy of electrons at a desired level by exploiting the quantum mechanical effects generated from electrons confined within a very small area (on the nanometer scale). If these electrons are all at a single energy level, it becomes possible to produce a power-saving laser, as energy waste is minimized. However, quantum-dot technology has yet to be put to practical use. Although this technology has been the subject of numerous studies, it remains difficult to equalize dot size and to increase dot density.

To address these problems, we have been conducting research using antimony, a material infrequently used to date. Last year, we were successful in creating a stripe-type antimony-based quantum-dot laser that operates in the 1.3-mm range (used in fiber-optic communications) at ambient temperature. To minimize cost, we used an inexpensive GaAs (gallium arsenide) substrate in this device.

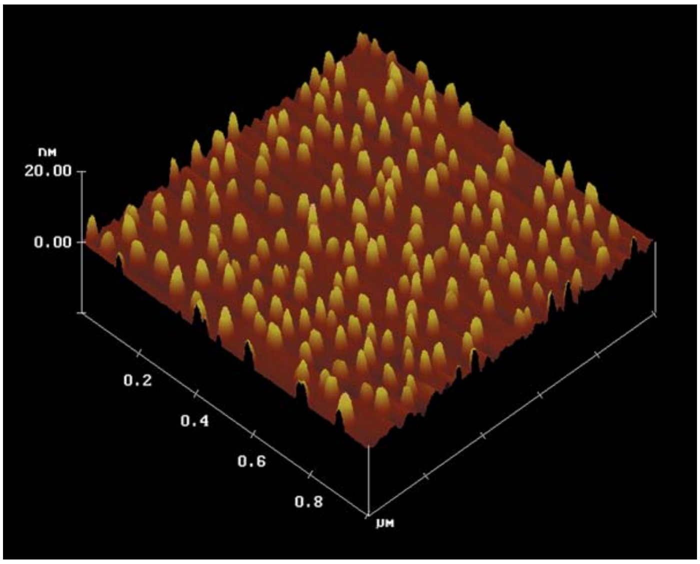


Figure 1: Quantum-Dot Example (observed by atomic force microscope)

2. Recent Research Results

A surface-emitting laser gives off light perpendicular to its substrate. Since this type of device would in theory offer lower power consumption and effective in-plane integration, it has been viewed as promising device for optical communications. Past research, however, yielded little success with surface-emitting lasers in the optical-communication wavelength range (1.3 to 1.55 mm). Demand was therefore high for research results that could lead to practical application of this type of device.

We constructed a surface-emitting laser through the application of antimony-based quantum-dot technology that had proven successful in stripe-type lasers. Figure 2 shows the basic structure of this surface-emitting laser. The active layer, as the emitting element, contains InGaSb (indium gallium antimonide) quantum dots. With conventional technologies, one drawback of the antimony-based quantum dot is its low density. However, we achieved sufficient gain for lasing through the development of a technique involving irradia-

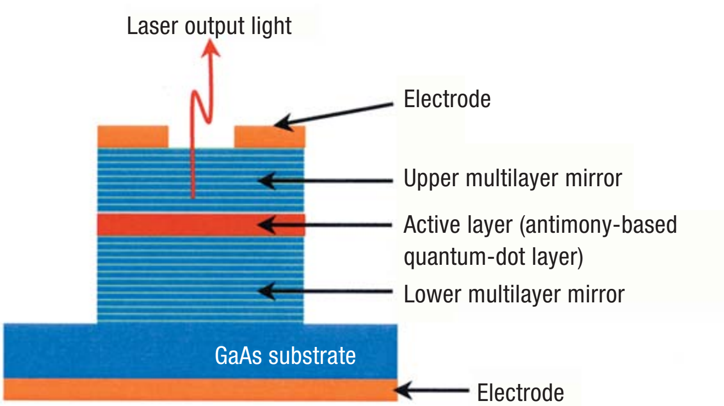


Figure 2: Basic Structure of Surface-emitting Laser (constructed by current group)

Optical Devices —

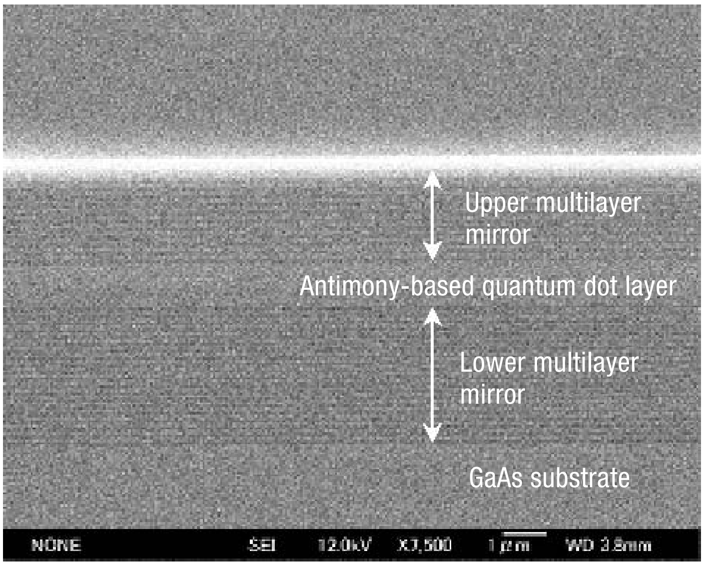


Figure 3: Electron Microscope Cross-sectional Image of Surface-emitting Laser (constructed by current group)

tion of the substrate with silicon atoms before the formation of quantum dots, increasing the dot density by 100 times or more. The upper and lower multilayer mirrors sandwiching the active layer feature a periodic structure of GaAs and AlAs (aluminum arsenide) films, achieving 94% or higher reflectivity near a wavelength of 1.3 mm. The use of GaAs in the substrate offers the advantages of lower device costs and easier multilayer mirror fabrication. Figure 3 is a cross-sectional image of our surface-emitting laser, taken with an electron microscope. As is clear in the figure, the upper and lower multilayer mirrors are clearly formed, sandwiching the active layer on the GaAs substrate.

Figure 4 shows the luminescence properties of the surface-emitting laser during current injection. Lasing is confirmed by the sharp peak at a wavelength of 1.34 mm, with a device temperature of approximately 10°C and an injected current of 700 mA. This is the longest lasing wavelength for a surface-emitting laser in the optical-communication wavelength range. Based on these results, I believe that antimony-based quantum dots will prove effective in long-wavelength lasers, enabling continuous lasing by a surface-emitting laser in the optical-communication wavelength range at ambient temperature.

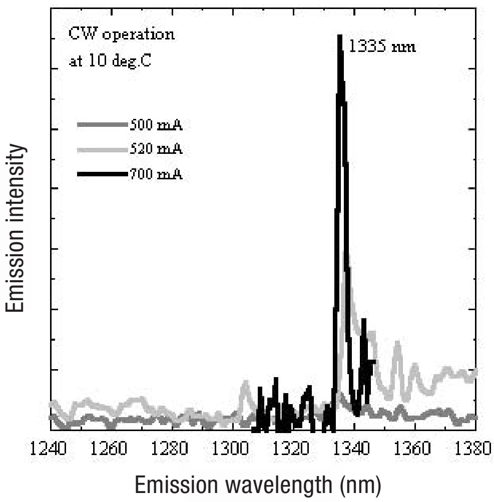


Figure 4: Lasing Spectrum

3. Conclusion

The use of quantum dots of antimony, a newly applied material, has enabled the previously elusive realization of a surface-emitting laser in the optical-communication wavelength range. Going forward, we will aim to improve performance in the 1.3-mm range, as we also pursue the development of a surface-emitting laser in the 1.5-mm range, a laser subject to little investigation to date. This was a risky R&D project relying on a little-used material, but we were able to achieve our goals within a very short time (essentially two and a half years), thanks to the use of the high-quality crystals prepared by the NICT Optical Device Technology Center. I would like to take this opportunity to express my gratitude to the Center staff involved in this project.

Finally, I should add that the research results presented here were formulated as a post deadline paper that was very well received at the International Conference on Indium Phosphide and Related Materials held at the end of May in Kagoshima.

Contributions to Numerous Fields through Up-to-date Cartographic Data and Additional

GIS Open Laboratories

1. Objectives

Through the addition of various types of information such as basic residential registration, cadastre information, and city topography to the latest cartographic data, the Geographic Information System (GIS) is expected to play a growing role in a wide range of fields—administration, environmental preservation, emergency medical care, disaster-prevention, welfare, education, sightseeing, logistics, and urban revitalization.

The NICT established a number of GIS Open Laboratories to promote the widespread use of GIS and to contribute to overall regional development.

2. Overview of Activities

There are three GIS Open Laboratories nationwide: in Yokosuka, Uji, and Okinawa; we have made these facilities available to companies, universities, research institutes, and local governments. These GIS laboratories are useful in GIS networking aimed at the accumulation and sharing of large volumes of cartographic data, in the development of technologies necessary for electromagnetic distribution of geographic information, and in R&D in applied technologies in other fields (such as disaster prevention, education, and welfare). These facilities are made available to help speed the arrival of an advanced information-communication society. Each laboratory has a staff of full-time members available to provide technical support.

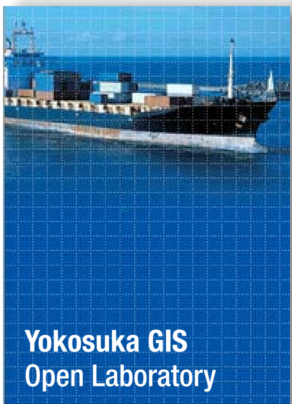
3. Overview of Facilities

The laboratories feature the following main facilities:

◆ **Yokosuka GIS Open Laboratory**
- Networked highly accurate positioning facility
- Logistical GIS facility
- Municipal application facility
- R&D facility for shared clearinghouse technologies
- R&D facility for efficient construction and sharing of spatial database
- R&D facility for shared applications

◆ **Uji GIS Open Laboratory**
- Experimental facility for regional GIS intranets
- Experimental facility for real-time video links

◆ **Okinawa GIS Open Laboratory**
- GIS facility for third-party facility management
- GIS facility for sightseeing and environmental applications
- Facility for image-based cartographic data updating



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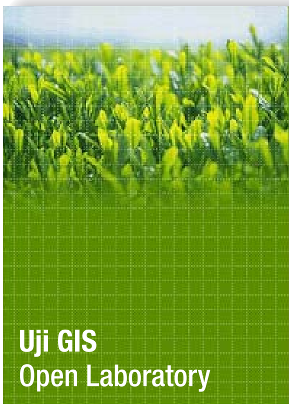

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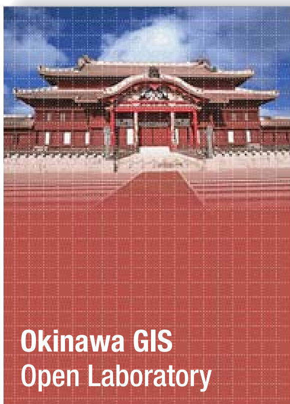

Contact:
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Supervisory department:
GIS Section, Open Laboratory Management Division,
Collaborative Research Management Department, NICT Shiba HQ TEL: 03-3769-0230

4. Main R&D Subjects

The laboratories specialize in the following main R&D subjects:

Yokosuka GIS Open Laboratory

- R&D in municipal GIS for publication on the Internet
- Review of new terminals for logistical GIS
- Function checks, verification function, and related experiments for practical use of a networked, highly accurate positioning facility
- Performance evaluation of highly accurate GPS; e.g., evaluation of positioning accuracy with environmental variation
- Research in applied technologies for advanced use of the clearinghouse system

Uji GIS Open Laboratory

- Development of procedures to create flood hazard maps
- Construction of networked cities to cooperate in rehabilitation and reconstruction in the event of earthquakes
- Urban area evacuation guidance system in the event of flooding
- Enhancement of the image-retrieval system in connection with disaster mapping
- R&D in technologies for the use of municipal GIS in the web environment
- R&D in GIS software for regional marketing
- Sightseeing information system
- Creation of GIS enterprises in Uji City
- Web-based GIS community data files established by residents

Okinawa GIS Open Laboratory

- Research in use of GIS in power-utility fieldwork
- Research in customer information management in power-distribution business
- Strategic agricultural and environmental monitoring through high-resolution satellite images
- Industry-academia-government joint research and studies of organizations promoting GIS
- Industry-academia-government joint research and studies of the distribution of spatial data