Compound semiconductor materials and devices and the fabrication of semiconductor nanostructures, search for new functions

Summary of Research

Fabrication of High-Performance Semiconductor Devices and Nanorods

Compound semiconductor materials and devices and the fabrication of semiconductor nanorods are the two major research themes at our laboratory. We fabricate next-generation semiconductor materials and semiconductor nanorods through a metal organic vapor phase epitaxy (MOVPE) apparatus and chemical synthesis, developing high-performance electro-optic devices that strategically exploit the functions of the new materials we create.

Compound Semiconductor Materials and Devices

One of our most notable achievements in recent years has been the development of highly-reliable InP/InGaAs, InGaP/GaAs heterojunction bipolar transistors (HBT). These transistors, boasting high current drive and high-frequency operation capabilities, are expected to serve as power elements for cell phones and optical communication devices.

The problem with conventional bipolar transistors lies in the difficulty of achieving high-frequency operation due to limitations in base doping concentrations. We overcame this problem by using a wide-band-gap semiconductor as the emitter and carbon as the p-type impurity in the base. Another obstacle to the successful creation of a high-performance HBT is the need for a high-quality interface; different materials are generally used for the emitter and base. Our laboratory has independently developed defect evaluation methods for semiconductor elements using Laplace Deep Level Transient Spectroscopy (DLTS) and Charge Transient Spectroscopy (QTS), using them in our development of high-performance semiconductor devices.

We have also succeeded in improving the reliability of HBT characterized by high base doping concentrations, which typically tend to deteriorate under high current conditions. We accomplished this by introducing an emitter modified with a structure, called a passivation ledge, to the transistor. In the area of optical devices, our laboratory is active in research and development involving powerful large-area LEDs for red, yellow, blue, and infrared. The semiconductors used for red and yellow LEDs are based on InGaP; for blue, InGaN; and for infrared, GaAs. Due to their long life and low power consumption, LEDs have gained popularity as environmentally-friendly illumination devices. The downside to conventional LED elements has been the small size of their effective surface areas, normally in the range of 0.3 to 0.5 mm².

By using Indium Tin Oxide (ITO) as an electrode—the material offers high transmittance of 80-90% in the visible range and extremely low electrical resistance—our laboratory was able to expand the effective area to 1 cm², as proudly demonstrated at SEMICON® Japan.

Research and development on ultraviolet (UV) LEDs has been gaining momentum both in Japan and abroad. In this area, our laboratory has independently developed an MOVPE apparatus that will enable the fabrication of a variety of high-quality metal oxide semiconductors suitable for use as wide-band-gap semiconductor materials. Our approach makes use of p-type nickel oxide (NiO)/n-type zinc oxide (ZnO) heterojunctions to fabricate UV-LEDs.

We have also developed a UV oxidation method in which deposited silicon oxide thin films are oxidized at low temperatures under UV-irradiated conditions, allowing us to develop a low-temperature fabrication technique for the high-quality oxide thin films required for IC fabrication on the flexible substrates expected to become the material of choice for next-generation electronics. It has also resulted in the successful development of a fabrication technique for a high-quality gate oxide on semiconductor

Keywords

Nanotechnology, compound semiconductors, LSI processing, metal organic vapor phase epitaxy (MOVPE), LED, heterojunction bipolar transistor (HBT), oxide semiconductors, deep-level transient spectroscopy (DLTS)

Affiliations

American Physical Society, Materials Research Society, Electrochemical Society, Institute of Electrical and Electronics Engineers (IEEE), Japan Society of Applied Physics

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surfaces previously incompatible with the fabrication of high-quality gate insulting films such as GaN or SiN. Currently, we are using this UV oxidation method to develop a base technology for printed flexible electronics fabrication, wherein oxide semiconductor integrated circuits are formed on flexible substrates by low-temperature oxidation of metals deposited by printing techniques.

**Advantages**

**Facilities Equal to Those of Corporate Counterparts and Our Own Business Ventures**

Both Professor Nozaki and Associate Professor Uchida have enjoyed extensive research careers in the United States, as graduate students and in corporate work, reflecting a natural inclination toward applied research. While most people would expect research at universities to focus heavily on basic research and place less emphasis on applications, our laboratory focuses on the whole process, upstream to downstream: in short, from basic research all the way to end-user applications.

Our ample experimental facilities and equipment underlie all our efforts. Our high-quality cleanrooms are equipped with a broad range of equipment, including the MOVPE, configured in close proximity to enhance productivity. Our facility offers resources significantly beyond the level of a single laboratory at a typical university, comparing favorably to corporate research facilities.

A unique laboratory characteristic is that we operate our own business venture. Named the NANOTECO Corporation (http://www.nanoteco.com/), it is directed by Professor Nozaki and Associate Professor Uchida. Its major role is to enable the commercial transfer of our research results through the sales and distribution of heterojunction high-frequency bipolar transistors and visible (including white light) and infrared LEDs.

**Future Prospects**

**Developing Oxide Semiconductor Heterojunction Devices and Micro Electro Mechanical Systems (MEMS) Energy Harvesting Devices using Compound Semiconductor Nanowires**

We plan to develop a novel oxide semiconductor heterojunction device by fabricating a heterojunction based on combinations of various oxide semiconductors, such as NiO and ZnO, followed by the development of a doping technique for oxide semiconductors to control carrier type and concentrations. We also plan to build on our past success in fabricating high-performance HBT and phototransistors and to develop MEMS by combining elements developed with energy-harvesting elements using nanowires capable of driving transistors without batteries.

While the main focus of our current research is semiconductors, our motto is “If it’s interesting, then study it!” True to our motto, we expect to continue producing remarkable results well into the future.