Dry Etching Technologies for 3D Sensors for Automobiles

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3D sensing devices for autonomous vehicles have seen major technical advances in recent years. Light Detection and Ranging (LiDAR) has emerged as the technology most compatible with these sensors, as it possesses characteristics that promise to enhance the functionality of autonomous driving.

Vertical Cavity Surface Emitting Lasers (VCSELs) are economical and compact enough to serve as light sources for LiDAR. Dry process is the key to VCSEL fabrication. However, this fabrication method poses various challenges. To produce these devices, we have been developing a high-uniformity etching technology, along with an Interferometry End Point monitoring system.

This article elaborates on the solutions we implemented to address these challenges.

1. Introduction

In recent years, advances in autonomous driving technologies, as well as a surge in adoption of electric vehicles, have been stimulating market demand in the automotive industry. Especially for autonomous driving, its success is highly dependent on its capability to consistently retrieve and process the 3D information of what is around the vehicle. This continuous information retrieval can be achieved by utilizing LiDAR technology, which enables 3D sensing of high accuracy. In fact, the LiDAR market for automotive applications is expected to increase from 1.5 billion yen in 2018 to 140 billion yen by 2024[1).

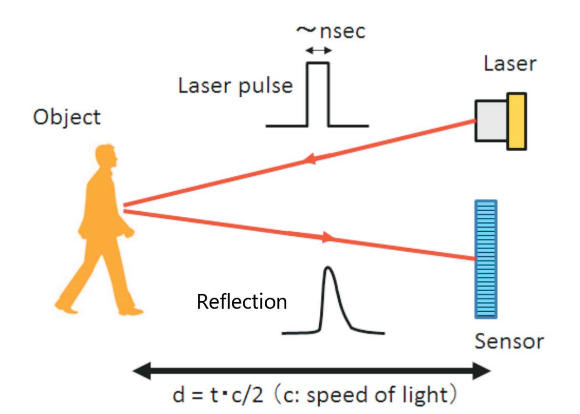

Fig. 1 Using LiDAR to measure distance

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LiDAR works by sending pulsed laser in the form of light to an object in order to gauge the distance between the sensor and the object (Figure 1). By measuring the time, also known as Time of Flight (ToF), taken for the reflected light to be detected via the LiDAR, the distance can be derived.

There are typically two types of LiDAR, as follows:

(a) Scanning LiDAR
  This type uses continuously pulsed laser emissions and a mechanical scanning

(b) Flash LiDAR
  This type uses a high-output single pulse laser and a 2D photo detector array

Unlike most other commercial methods, which use cameras or millimeter-wave radar, LiDAR uses infrared laser. Refer to Table 1 for a list of the features of these sensors. Since LiDAR uses infrared light, which has shorter wavelength compared to millimeter-wave radar, it is able to detect its surroundings at higher spatial resolutions, making it better able to detect objects such as pedestrians and bicycles. Even though performance of LiDAR drops under unfavorable weather conditions such as fog or rain, night-time detection performance is still comparable to other commercial methods.

	Camera	Millimeter-wave radar	LiDAR
Measurable range	○	◎	◎
Spatial resolution	○	△	◎
Weather resistance	△	◎	○
Detectability in dark	○	◎	◎
Object recognition	◎	△	○

Table 1 Comparisons of sensors

However, LiDAR must be kept as compact as possible so as not to compromise car design. At the same time, it must be affordable compared with other commercial methods. These requirements can be achieved by using compact infrared semiconductor laser diodes (LDs) as the light source for LiDAR. The market for 3D sensing LDs is expected to grow from 18 billion yen in 2018 to 70 billion yen by 2024 as adoption of LiDAR increases[2)].

This paper introduces the features of semiconductor LDs that are used in LiDAR systems. It also describes the dry process technologies used to address the challenges faced in manufacturing semiconductor LDs.

2. Semiconductor Lasers (EEL and VCSEL)

Semiconductor LDs are able to meet the requirements as a high-performance, compact, and low-cost light source for LiDAR systems because of the following advantages they offer:

(1) Compact and rugged (approximately 300×200×100 μm^3)
(2) High energy conversion efficiency and low power consumption
(3) High-speed direct modulation at 10 GHz or faster
(4) Long service life, in the range of tens of thousands to 1 million hours with high reliability
(5) Cost effective mass production (around $1/unit)

In addition, LDs used for use in LiDAR are classified into two basic types; namely the Edge Emitting Laser (EEL) and the Vertical Cavity Surface Emitting Laser (VCSEL). Table 2 summarizes the differences between the EEL and VCSEL types.

In EEL, an optical waveguide on the epitaxial layer allows light to be confined to a relatively narrow line as shown in Figure 2(a). The two ends of the crystal are then cleaved to form smooth and parallel edges that results in a Fabry-Perot resonator. The light emitted travels along the waveguide and is reflected several times from each end-face before it exits.

	EEL	VCSEL
Output direction	Edge emission (Horizontal direction)	Surface emission (Vertical direction)
Transverse mode	Elliptical beam	Circular beam
Longitudinal mode	Mode hopping	Single mode
Threshold current	<10mA	<0.1mA
Output power	~500mW	~10mW

Table 2 EEL vs. VCSEL

In VCSEL, the active layer is sandwiched between two highly reflective mirrors (also know as distributed Bragg reflectors or DBRs). It is made up of several quarter-wavelength-thick layers of semiconductors that are of alternating high/low refractive index, as shown in Figure 2(b).

The reflectivity of these mirrors is typically more than 99%. As a result, the light oscillates perpendicular to the layers and escapes through the top (or bottom) of the device. Current and optical confinement is typically achieved through selective oxidation of Al-rich layers, through ion-implantation, or through both methods.

The VCSEL structure makes it possible to form a resonator without cleaving the substrate. It is also possible to evaluate the LD's characteristics during the manufacturing process. In addition, VCSELs can be manufactured at a lower cost compared with other types of LDs and they can be combined into 2D arrays. These characteristics combine to make them highly suitable for mass production.

Below is a list of additional benefits offered by VCSELs:

- **System miniaturization.** Integration at the wafer-level is possible, which in turn simplifies packaging. By combining a VCSEL with a micro lens array, the system can be made very compact and thus pose no constraints on car design.

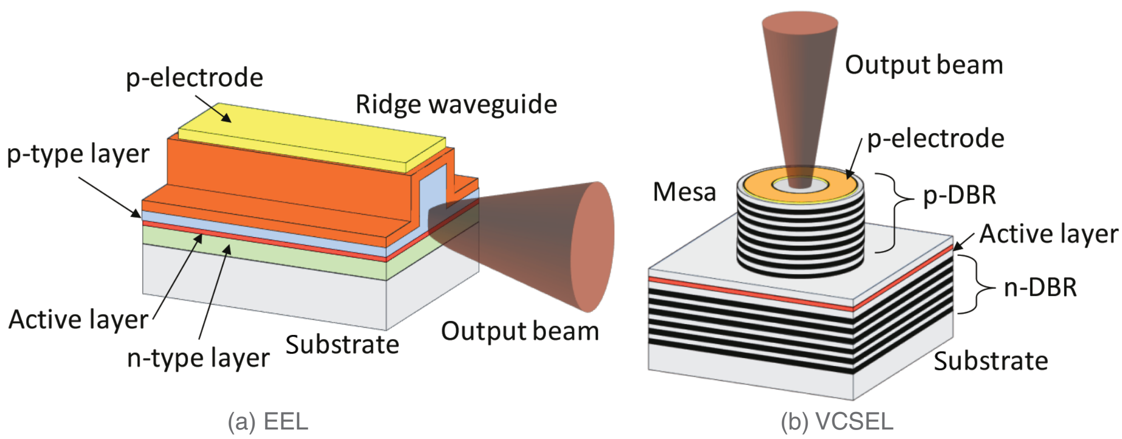


Fig. 2 Schematic of laser diode structure

- **Low power consumption.** Due to the small threshold current required by VCSELs, lower power consumption is possible.
- **Longer distance measurement.** Despite the small output of an individual VCSEL, an array of VCSELs can yield a large output, which then provides longer distance measurements.
- **Stability.** Since its laser resonator is determined by two DBRs, VCSEL suffers less heat-caused emission spectrum changes compared with other LDs. This makes VCSEL less susceptible to external influences, giving it more stability.

The above benefits describe the characteristics of VCSEL technology, which make VCSELs preferable as a light source for LiDAR. LiDAR performance can be further improved by more fully utilizing the LDs in the future.

3. VCSEL Process Challenges and Solutions

Figure 3 provides an overview of the dry process steps for manufacturing VCSELs.

(1) The DBR multi-layer and active layer films are epitaxially grown on a GaAs substrate. The DBR layer contained several pairs of AlGaAs/GaAs layers.

(2) A mask pattern is formed by using photolithography and etching.

(3) A cylindrical shape, also known as a "mesa," is fabricated by dry etching the epitaxial layer.

(4) The AlGaAs layer near the active layer is oxidized and constricted using a wet oxidation process. (This oxidation constriction layer plays a critical role in determining the characteristics of VCSEL as a structure that confines current and light.) Dielectric film is then deposited on the sidewall of the mesa for protection.

(5) Lastly, electrodes are fabricated on the n- and p-type layers.

At present, controlling the oxidation constriction layer is difficult, and there is no technology that can any concrete solutions. Instead, by improving the accuracy of forming the mesa shape, oxidation effect might be minimized.

As explained above, dry etching technology is used to form the mesa shape. ULVAC has solid performance records in etching many types of VCSELs[3], and this paper describes the controllability of etched profile and uniformity

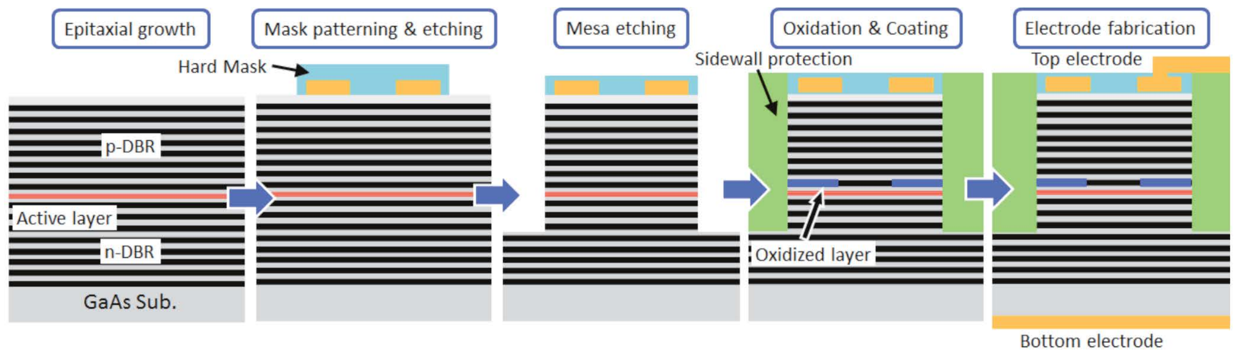
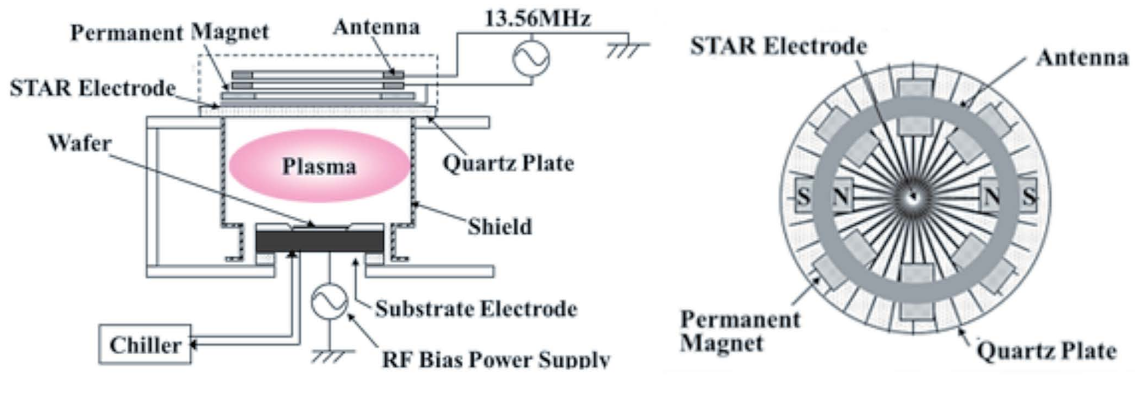


Fig. 3 VCSEL process flow



a) Process chamber b) ISM antenna

Fig. 4 Schematic of dry etching equipment (NE series)

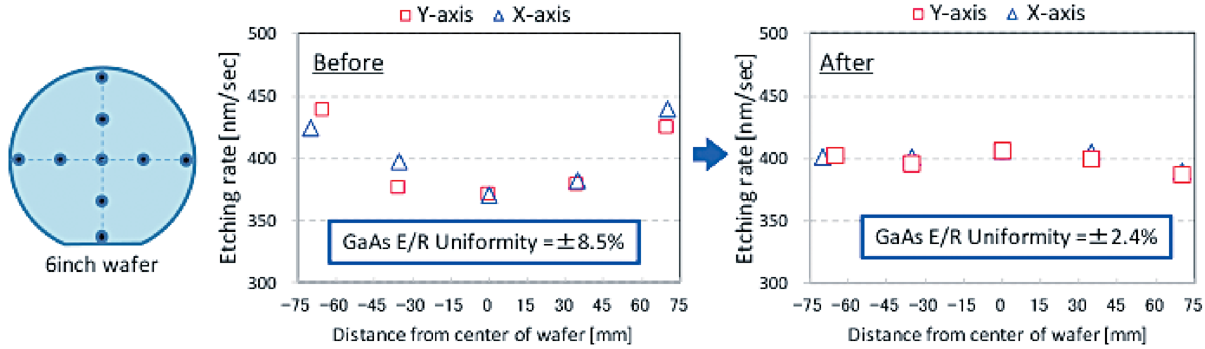


Fig. 5 GaAs etching uniformity

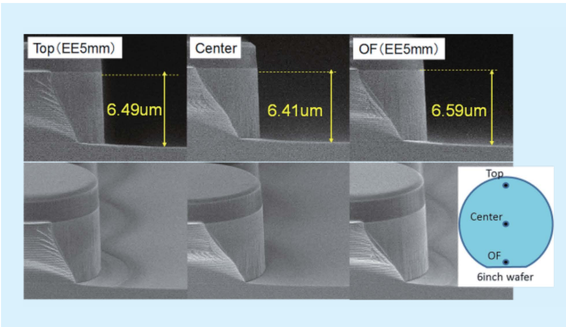


Fig. 6 VCSEL etched uniformity in 6-inch wafer

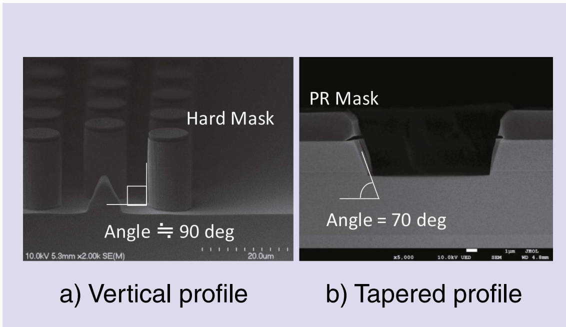


Fig. 7 Etched profile of VCSEL observed by SEM

within the wafer surface. Chlorine gas is used for etching groups III–V compound semiconductor materials, such as GaAs used in VCSELs. Because reactive conditions for dry etching are primarily used for etching AlGaAs/GaAs multi-layer films, it is difficult to control the etched profile and uniformity within the wafer surface. Furthermore, in etching compound semiconductors, adjusting dry etch conditions alone cannot be used to control both the etched profile and uniformity.

In the NE dry etching system, the Inductively Super Magnetron (ISM) method is used for the antenna structure, as shown in Figure 4. This antenna structure can optimize plasma distribution and produce an extreme uniformity of 3% or better within the etching of a GaAs wafer surface, as shown in Figure 5. Even in VCSEL epitaxial structures, a uniform etched profile has also been obtained within the entire wafer, as shown in Figure 6.

On the other hand, since the mesa shape affects characteristics such as beam profile and output power, a wide variety of shapes is required according to the device application. By optimizing the mask structure and process conditions, it is possible to etch the wafer surface into any

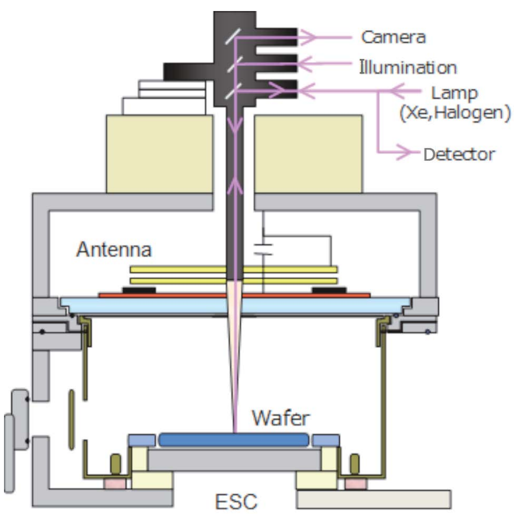


Fig. 8 Schematic of IEP system

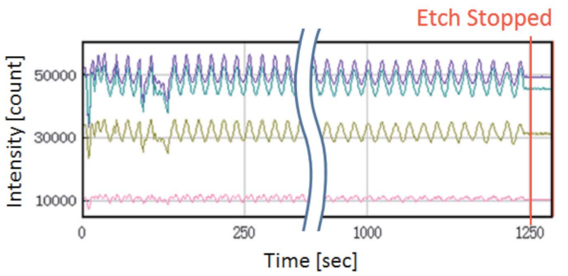


Fig. 9 IEP signals

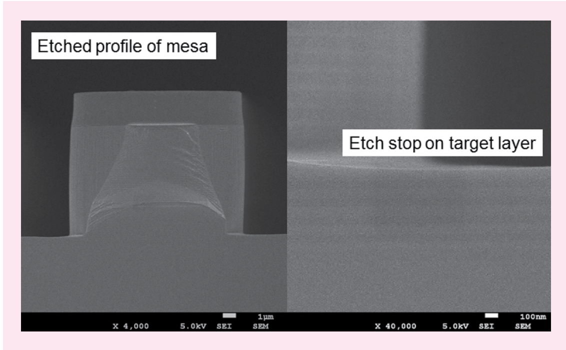


Fig. 10 Etch stopped at target layer

required shape, from tapered to vertical angle, as shown in Figure 7.

To control the mesa depth, the Interferometry End Point (IEP) method shown in Figure 8 can be used to accurately control etching depth. Figure 9 shows the interference waveform obtained using this system. The figure shows how the stacked structure, including the DBR layers, have been etched. By counting the number of DBR pairs while monitoring this waveform, it is possible to stop etching at the desired depth. The waveform in which the IEP system was actually used to count the number of DBR pairs, shown in Figure 9, and the SEM observation result shown in Figure 10 confirms that etching was stopped at the target layer based on to the waveform.

A selective etching technology that utilizes the difference in the composition ratio in semiconductor materials such as GaAs/AlGaAs and GaAs/InGaAsP would also be feasible. Combining such a technology with an IEP system or optical emission spectrometer (OES) could satisfy the need for even greater etching accuracy.

4. Conclusion

Dry process technology was observed to be the key in fabricating LDs for use as light sources for LiDAR. By optimizing the process conditions and the structure of the antenna in the dry etching system (NE-series), we improved the uniformity of the etched profile of the entire wafer, as well as control the etched profile of VCSEL’s mesa.

In summary, ULVAC can provide highly accurate dry etching technology for fabricating a uniform profile over the entire wafer. These technologies are expected to solve the problem of LDs product, which expanding market scale.

References

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