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Micro-Aperture GaAs Surface Emitting Laser for Near Field Optical Data Storage

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1. Introduction

An optical near-field technique has been attracting much interest for an ultra-high density optical memory [1]. One of the authors (K. Goto) proposed a tera byte optical memory system using a vertical cavity surface emitting laser (VCSEL) array [2]. We proposed a metal aperture VCSEL for producing optical near field with high efficiency as shown in Fig. 1 [3]. Recently, a VCSEL integrated in GaAs near field probe was demonstrated [4]. Also, we carried out two-dimensional finite element analysis for a micro-metal aperture [5] and predicted the spot size of optical near field can be as narrow as 100 nm beyond a diffraction limit.

In this study, we fabricated a 0.85 μm wavelength GaAs VCSEL with a Au micro-aperture on the top surface by using focused ion beam etching. A radiated power from the micro-aperture was evaluated.

2. Structure of micro-aperture VCSEL

Figure 2 shows the schematic structure of a fabricated metal micro-aperture VCSEL. A Au thin film on the top of a p-type distributed Bragg reflector (DBR) shades an emission light and the optical near field is produced at a micro-aperture opened in the Au film. The p-type DBR consists of 11 pair, which is about a half of a conventional mirror design in VCSELs. When we design the phase matching between the top DBR mirror and the metal, the composite mirror of Au and the top DBR gives us a high reflectivity. The calculated reflectivity of the Au-film (100 nm thick) loaded an 11 pair DBR without the micro-aperture is 99.5%, which is comparable to that of a 22 pair DBR without metal terminating. An AlAs layer is oxidized selectively for current confinement and for single transverse mode operation. The micro-aperture is placed at the center position of the Al oxide aperture. The emission wavelength of the VCSEL is 850 nm in the present experiment. Note that the computed result can be available by scaling down the aperture with reducing the wavelength. This means that the micro-aperture can be reduced for shorter wavelengths.

We fabricated VCSELs with ~100 nm square metal apertures in a 100 nm thick Au film. For fabricating micro-apertures, we have used a focused ion beam (FIB) etching which uses a Ga^+ spattering effect. The inset of Fig. 2 shows the AFM image of a fabricated metal aperture VCSEL. The device has a 7~8 μm oxide aperture for lateral confinement.

3. Device characterization

Figure 3 shows I-L characteristics of a VCSEL before and after fabricating a 400 nm square micro-aperture on the Au film. The threshold current is 1.7 mA corresponding to 3 kA/cm^2 of threshold current density. We measured the output power using a Si detector with 100 mm^2 area, separated by about 3 mm from the device. We estimate that about 50 percent of output power radiated from the aperture is detected, based on an assumption of its spherical radiation. Thus, the output power from the 400 nm aperture is estimated to be 10 μW.

Figure 4 shows the intensity profile of near field patterns below the threshold for various aperture sizes between 100 nm and 1 μm. The near field patterns were measured by using a conventional optical microscope, resulting in a spatial resolution of about 1 μm. Broad emission with a full width at half maximum (FWHM) of 7 μm is originated from light through the Au film. The peak shown on the center of the emission light should be from the radiation from the aperture. Its FWHM is about 1 μm, which is equal to the diffraction limit of the optical microscope we used for this measurement. It is notes that the peak intensity may be reduced by the diffraction-limited resolution. Thus, the real peak intensity should be much higher than that of the background light through the Au film. The output power radiated from the aperture is reduced with decreasing the aperture size. The output power density of a 400 nm-aperture VCSEL is ~0.1 mW/μm^2, which is insufficient for optical recording in disk memories. One way to increase the power density is to reduce the oxide aperture in the cavity. For example, if 1×1 μm narrow single mode condition is satisfied, the power density may be increased by a factor of 50. Another possible way is to use a surface plasmon, enhancing optical near-field [6]. We may put a metal tip in the micro-aperture as shown in Fig. 5.

4. Conclusion

We have demonstrated a VCSEL emitting at 850nm with a metal micro-aperture for the first time. We successfully realized the fabrication of micro-apertures of 100 nm by using focused ion beam etching. The employed composite mirror design of Au/DBR gives us a high reflectivity resulting in a reasonably low threshold current density operation of 3 kA/cm^2. By increasing the power density of optical near field, we can expect read/write functions of the propose device for optical memories.

Acknowledgement

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References

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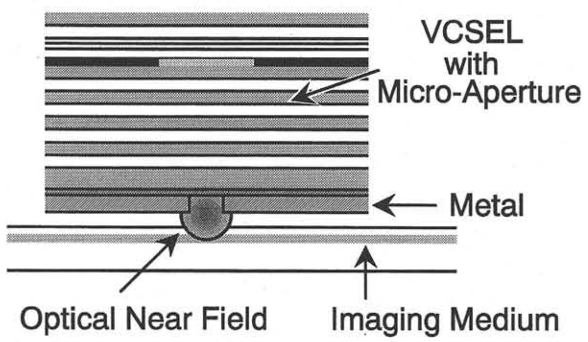

Fig. 1 Model of an optical memory head consisting of a VCSEL with a metal micro-aperture

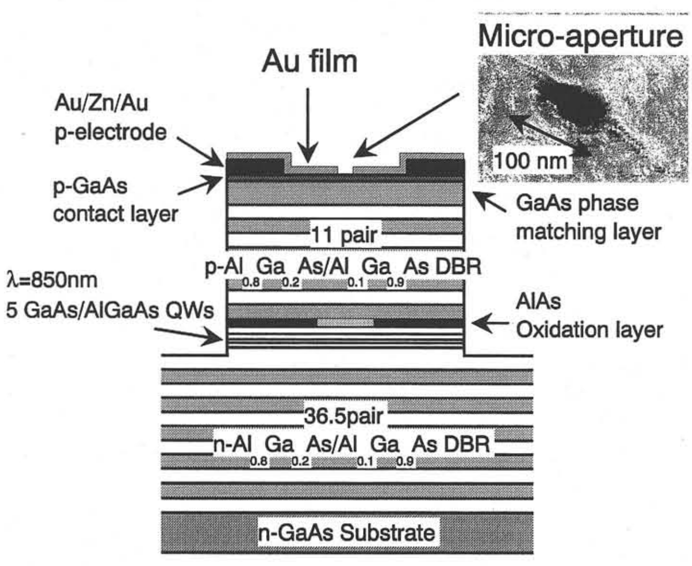

Fig. 2 Schematic structure of a VCSEL with a metel micro-aperture

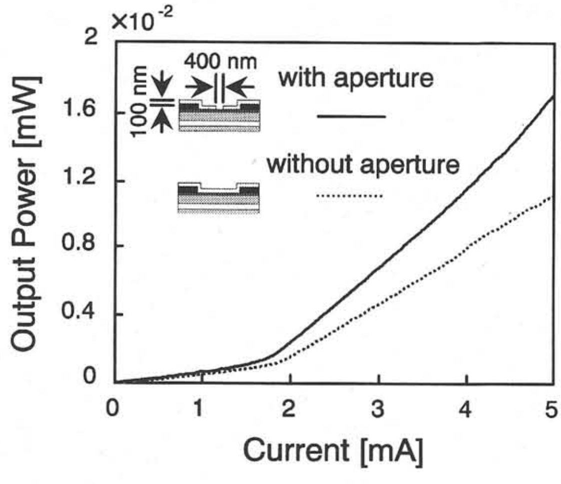

Fig. 3 I-L characteristics of a VCSEL with 400 nm square aperture or without aperture at 100 nm thick Au film.

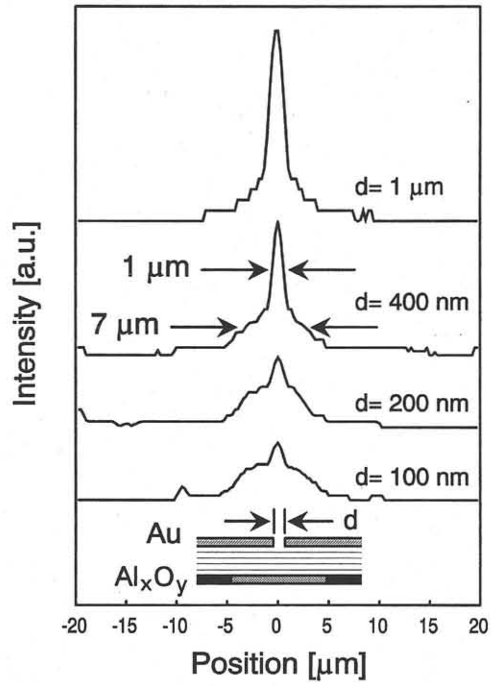

Fig. 4 Near field pattern of VCSELs with various aperture sizes

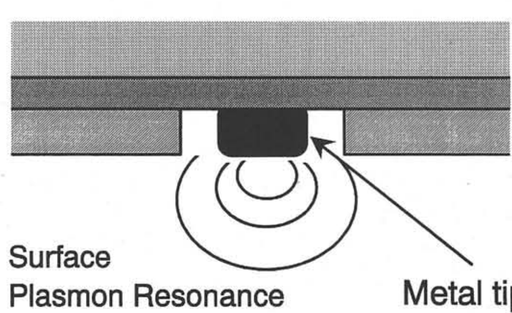

Fig. 5 Enhancement of the optical near field using surface plasmon at a metal tip put in the micro-aperture