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Light Emitting Diode Array Prepared by Epitaxial Film Bonding

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1. Introduction

Integration of devices having different functions is one of important fields to investigate for development of a compact device-system providing high performance. Bonding thin film by intermolecular force is one of suitable techniques to integrate various device elements, which are formed of dissimilar materials. High density light emitting diode (LED) printer printheads have been developed [1], and requires integration of LEDs and silicon (Si) integrated circuit (IC) drivers. We have concentrated our study on compound semiconductor epitaxial film bonding (EFB) on the Si-IC-driver wafer. In the EFB process, roughness on bonding pair surfaces must be one of the key parameters to obtain large enough bonding strength for LED array fabrication using photolithography and etching process. This study focused on EFB quality depending on surface roughness, and the LED array integrated with the Si–IC driver was fabricated by EFB based on the result of surface roughness characterization.

2. EF characterization

Epitaxial film preparation

Epitaxial films (EFs) were prepared using selective etching of a sacrificial layer that was formed of aluminum arsenide (AlAs) between the GaAs wafer and the EF layer [2, 3]. The EF layer has a double hetero epitaxial layer structure. Rectangular island structures were formed by mesa-etching and exposed the AlAs layers at the mesa-etched surfaces. Individual support materials were prepared on the top of each mesa-etched island structure. An adhesive sheet was attached on the individual support materials. The EFs were lifted off from the GaAs and transferred to the adhesive sheet.

Figure 1 shows the result of atomic force microscope (AFM) measurement on the EFB surface; the scanning area was 5μm squares. As shown in Fig. 1, very smooth surface was prepared. Surface roughness (typical peak-to-valley value (R_{PV})) of the bonding surface is as small as 1-2nm. No residues of the sacrificial layer and no particles were observed on the bonding surface.

EFB quality characterization depending on Surface roughness

The bare Si wafers were covered by several kind of materials: spin-coated organic film, sputtered oxide thin film, and plasma chemical-vapor-deposited (CVD) nitride thin film in order to prepare various surface roughness. The surface of the thin film layers formed on the Si wafer were measured using AFM.

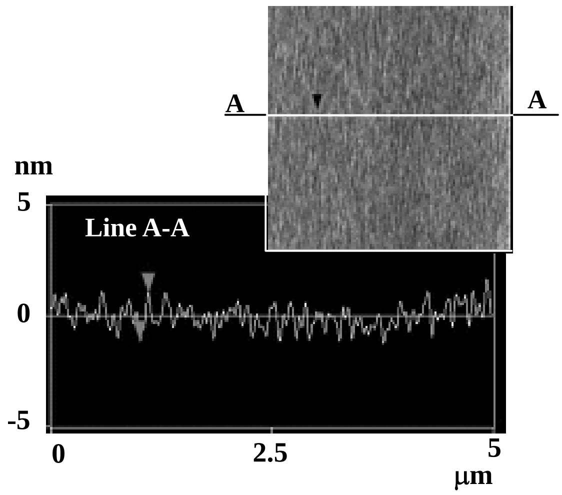

Fig. 1 Surface roughness on the EF measured with AFM.

Figure 2 shows roughness of the tested surface; surface roughness indicates typical peak-to-valley height (R_{PV}). Tested surfaces provided R_{PV} in the range from 1nm to 14nm. The EF could not be bonded on the bonding surface when R_{PV} was larger than 10nm (case (c)). The EF could be bonded on the bonding surface when R_{PV} was around 5nm (case (b)), but EFB strength was weak and the bonded EFs came off form the bonded surface during LED fabrication process. The bonding surface of R_{PV}=1nm (case (a)) provided large bonding strength and no release of the EFs from the bonded surface happened in the LED fabrication process. Spin-coated organic film layer provided surface with R_{PV} ~1nm. The test result indicates that a surface roughness of R_{PV} ~ 1nm is required to fabricate LED array using EFB.

3. LED array preparation

The EFs supported with the support material were pressed to bond on the flattened area with R_{PV} ~ 1nm on the driving IC wafer. After the EFB process, the support materials were removed. The bonded EFs were mesa-etched to form the 600 dots-per-inch (dpi) LED array; the spacing between the centers of the adjacent LEDs was designed 42.3μm.

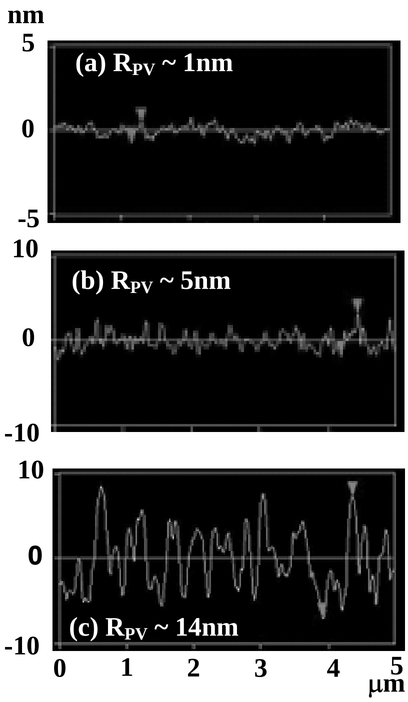

Fig. 2 Surface roughness measured with AFM on the tested surface.

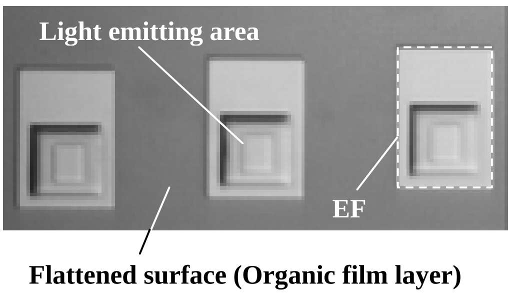

Fig.3 Microscope photograph of the array of the EFs on the Si driving IC wafer.

Figure 3 shows a microscope photograph of the array of the EFs to prepare LED array on the Si driving IC wafer on the fabrication process before forming contact electrodes of the LEDs and wirings to connect the LEDs and the driving IC. As shown in Fig. 3, no cracks and no voids were observed; EFB quality was proven high enough to fabricate the LED array.

Figure 4 shows the LED array integrated the driving IC chip mounted on a printed circuit board (the photograph was taken in a dark place); 4992 LEDs are on the printed circuit board for A4 size print. In Fig. 4, all the LEDs are switched on. Note that no bonding wires but metal thin film wirings are used to connect the LEDs to the driving IC. As shown in Fig. 4, all the LEDs were well controlled by the driving IC. Performance test showed high enough emitted light power (P_{LED}) efficiency and small enough P_{LED} variation to apply the LED array in the LED-printer printhead; typical P_{LED} was 47 μW at an LED current of 1mA and P_{LED} variation was as small as ±7%. The large P_{LED} efficiency and small P_{LED} variation also indicate that quality of EFB performed in this study was high enough for the LED fabrication.

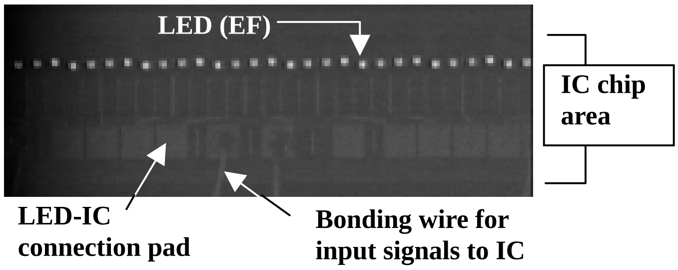

Fig. 4 EF LED array bonded on the Si driving IC chip. The chips are mounted on the printed circuit board.

4. Conclusions

We have focused on surface roughness on the bonding area to clarify suitable bonding surface to obtain large EFB strength to fabricate the LED array integrated with the Si IC driver using EFB. Based on the characterization of the EFB quality depending on surface roughness, we have fabricated the 600 dpi LED array integrated with the Si IC driver. We have proven that the LED array proved good enough performance to use in the LED-printer printhead.

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