Integration of III-V Microscale Light-Emitting Diodes for Cell-Sized Optical Wireless Electronics

CNF Project Number: 900-00

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Primary CNF Tools Used: Odd hour evaporator, ABM contact aligner, Oxford 81 etcher, AJA sputter deposition tool, P10 profilometer, RTA-AG610, Heidelberg mask writer DWL2000

Abstract:

Opto-electric circuits comprising light emitting diodes, photovoltaic cells, electric circuits etc. have attracted increasing attention and have found broad applications in fields ranging from displays to bio-integrated systems. A transfer technique to integrate optical and electrical devices together is required. Here we present a 4-inch wafer-scale aligned transfer method for integrating micro-LEDs with silicon circuits. This method demonstrates both high transfer yield and high alignment accuracy.

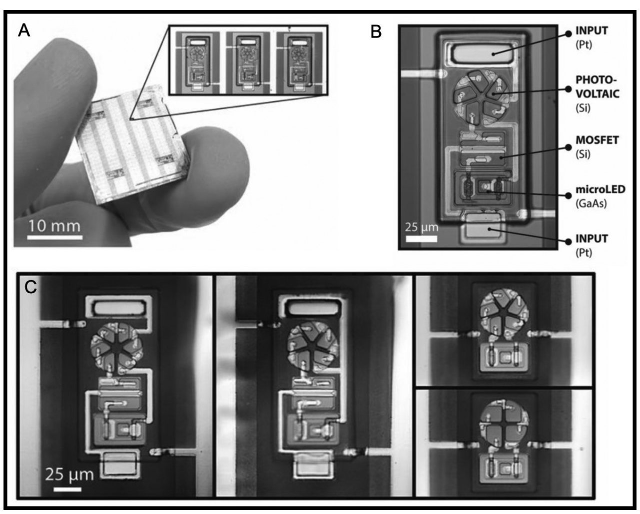

Figure 1: (A) Image of a chip containing thousands of integrated optical wireless integrated circuit (OWIC) sensors. (B) Optical image of an OWIC sensor with components labeled. (C) Image of various OWIC sensors with different functions.

Summary of Research:

Inorganic microscale light-emitting diodes (micro-LEDs) are broadly used in optoelectronic systems because of their high efficiency, color purity and reliability. Our group has recently developed a platform combining both inorganic micro-LEDs and electric circuits: optical wireless integrated circuits (OWICs) [1] (Figure 1). The OWIC sensors are approximately 100 µm across, which is microscopic in size, and can be used for a wide range of applications such as biosensing.

To integrate the micro-LEDs and silicon-based devices into the same circuit, a challenge must be met: high quality inorganic micro-LEDs are commonly grown on non-silicon substrates such as gallium arsenide (GaAs), while the electric circuits are fabricated on silicon substrates. Therefore, effective transfer methods are required. We develop an approach for transferring GaAs micro-LEDs from their native substrates to silicon substrate at wafer scale.

The micro-LEDs are fabricated on a commercially purchased 4-inch GaAs LED epitaxial wafer. The epitaxial structure is composed by p-GaAs layer, multiple quantum wells (active region) and n-GaAs layer. We first etch the GaAs epitaxial structure down to the n-GaAs layer to expose GaAs by citric acid wet etching. We then deposit the Ti/Pt metallic contact on the p-GaAs layer using the odd-hour evaporator. Following that, Au/Ge/Ni metallic contacts are deposited on the n-GaAs layer using the AJA sputter deposition system. We then etch the GaAs epitaxial structure down to the bulk substrate to outline the micro-LEDs using citric acid wet etching. In the end, the GaAs wafer is annealed in RTA-AG610 for better n-contact.

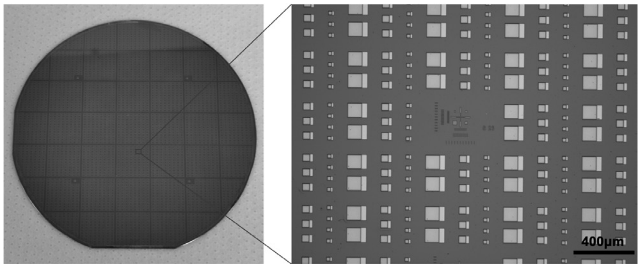

Figure 2: Fabricated GaAs micro-LEDs on a 4-inch GaAs wafer.

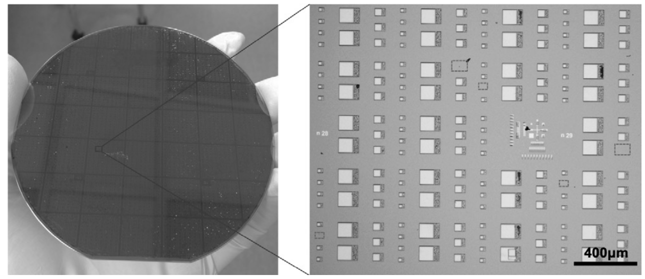

Figure 3: Transferred GaAs micro-LEDs on a 4-inch silicon wafer.

Figure 2 shows micro-LEDs of various sizes.

We then spin-coat PMMA onto the micro-LEDs as the protection layer and bond the 4-inch GaAs wafer with a transparent carrier wafer using a low melting-point thermal plastic polymer. Then we place the stack into citric acid to etch away the bulk GaAs substrate. After that, we have micro-LED arrays attached to the transparent carrier wafer. We then build up an aligning and bonding system based on the ABM contact aligner and a homemade heat stage. Using the aligning and bonding system, we first align the micro-LEDs with the features on the target substrate and then bring the micro-LEDs into contact with the target silicon substrate.

In the end we melt the thermal plastic polymer on a heat stage allowing the removal of the carrier substrate. The polymer residue is etched away in acetone. The result is aligned micro-LEDs transferred onto a 4-inch silicon wafer (Figure 3).

The transfer yield of this method is promising.

We transferred micro-LEDs in varied sizes to a bare silicon substrate (no adhesion layer) with high yield. The dashed boxes in Figure 3 indicate the few missing micro-LEDs, which are a small fraction of the total. The alignment accuracy is quantified by thousands of alignment marks distributed across the wafer. They show our method has reasonably precise alignment (~1µm). This wafer-scale transfer method will make possible new classes of integrated wireless sensors and optoelectronic devices fabricated across a full 4-inch wafer.

References:

[1] Cortese, Alejandro J., et al. "Microscopic sensors using optical wireless integrated circuits." Proceedings of the National Academy of Sciences (2020).