Transfer Printing of InGaN/GaN Quantum-Well Based Light Emitting Diodes

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Abstract: We demonstrate the transfer printing of an InGaN/GaN-QW based LED on a silicon substrate, emitting around 470 nm. This result is the first step toward heterogeneous integration of GaN-based devices on CMOS-compatible SiN photonic circuits.

1. Introduction

Integrated light emitting diodes (LED) and lasers are widely researched today, targeting a wide range of applications such as biomedical sensing, optical coherence tomography, visible light communication or quantum clocks. However, most of the integrated light sources currently available operate at telecom wavelengths, which is not ideal for such applications asking for light sources operating in the visible and near infrared range (400-1100 nm). In this context, researchers aim to use relatively wide bandgap III-V materials such as gallium nitride (GaN) or gallium arsenide (GaAs) to build devices working in this region of the electromagnetic spectrum. For instance, InGaN/GaN multi-quantum-well (MQW) based LEDs are a key technology and allow to generate light at wavelengths from 450 nm to 650 nm [1]. Nevertheless, III-V based devices remain difficult to integrate on scalable and low-cost CMOS-compatible photonic platforms in silicon or silicon nitride. Here we demonstrate the transfer printing of an InGaN/GaN-quantum well based LED on a silicon substrate, emitting around 470 nm. This result is the first step toward heterogeneous integration of GaN-based devices on CMOS-compatible silicon nitride photonic integrated circuits. Micro-transfer printing has already been successfully used for many applications and platforms, including the heterogeneous integration of GaN LEDs grown on foreign: silicon [2] and sapphire [3] substrates, making the quality of the III-V lower compared to devices grown on bulk substrates. For high current density operation, more typical for laser diodes, high crystal quality and low dislocation density structure is essential. Here we show a successful transfer procedure of the III-nitride light emitter grown on bulk GaN substrate.

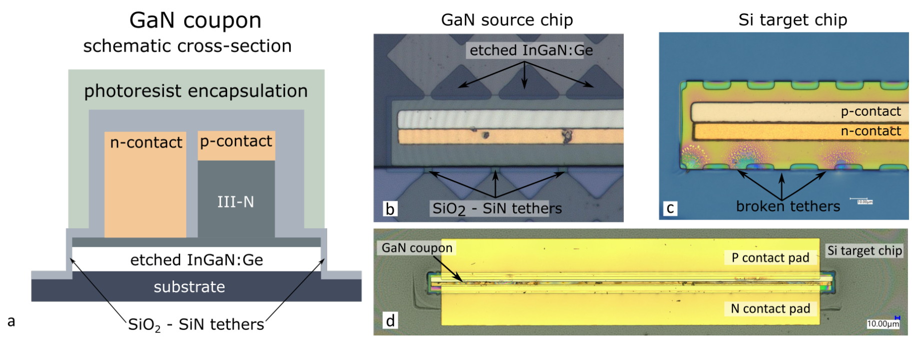

Fig. 1. a) Schematic representation of the cross-section of a GaN coupon on the source sample. b) GaN LED coupon after releasing, ready to be transfer printed. c) GaN LED coupon after transfer printing on a silicon target. d) Microscope image of the transfer printed GaN coupon on the Si target chip, with additional metal contact pads.

2. Fabrication of the devices

The devices consist of a GaN-based semiconductor stack including n-doped layers, a QW structure and p-contact layers. An extra release layer of heavily doped (>10^{20} cm^{-3}) InGaN:Ge is inserted between the substrate and the first n-doped layer of the diode. Once patterned, the devices are encapsulated in silicon nitride and silicon oxide. At this point, the devices can be released and kept suspended by mechanical tethers. Figure 1 (a) shows a schematic representation of a cross-section of such a device. Removal of the InGaN:Ge layer was achieved through electrochemical etching [4]. Since etching conditions are defined by electron concentration in each layer, large difference between germanium concentration in InGaN:Ge and n-type doping in other layers, resulted in desired high etching selectivity. This way InGaN:Ge could be completely removed leaving the III-nitride structure on top of it intact. The 1 mm by 50 µm coupons are then transfer printed onto the silicon target sample, which is covered with a thin (<100 nm) BCB adhesive layer. More details about the transfer printing technique can be found in [5]. Figures 1 (b) and (c) show microscope pictures of the device before and after transfer printing. The SiN encapsulation is removed using reactive ion etching, after which the sample is planarized by spincoating and hard-baking a thick layer of BCB. By etching back this layer, the metal contacts are opened up again, and can be contacted with a lithography and metallization step, enabling more convenient probing and measurements.

3. Measurement results

To demonstrate the LED operation of the printed device (Fig. 1(d)), and check the optical spectrum, the device was measured by applying a DC bias via probes connected to a power supply. Amplified spontaneous emission could visibly be observed as blue light emanating from the device, for sufficiently strong bias (6 V and 350 mA). This can be seen in Fig. 2(a). The light was captured with a cleaved multimode fiber, positioned vertically above the GaN coupons. The multimode fiber was connected to an optical spectrum analyzer to measure the spectrum of the emitted light. Fig. 2(b) shows the spectrum centered around 470 nm with a 10 dB optical bandwidth of 54 nm.

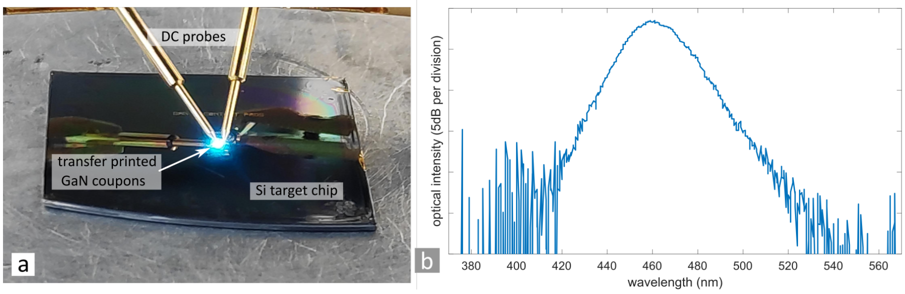

Fig. 2. a) Picture of probed chip, where amplified spontaneous emission can be observed as visible, blue light. b) Measured optical spectrum of the light captured from a GaN coupon with a multimode fiber.

4. Conclusions

In this work we have demonstrated the transfer printing of an operational InGaN/GaN based LED emitting around 470 nm on a silicon substrate. This result is the first step toward the heterogeneous integration of GaN-based devices on complex CMOS photonic circuits [6] for applications requiring visible wavelengths.

References

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