Microscale Broadband Optical Upconverter

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Primary CNF Tools Used: Odd Hour Evaporator, ABM Contact Aligner, Oxford 81 Etcher, AJA Sputter Deposition Tool, Hot Press, Heidelberg Mask Writer DWL2000, Oxford Cobra ICP Etcher, PT770 Etcher

Abstract:

Optoelectrical materials/devices that convert long-wavelength light into shorter wavelengths have gained increasing interest in fields like bio-sensing and infrared imaging [1]. Here we present a microscale optical upconverter made by heterogeneously integrating Si photovoltaics (PVs) and GaN light emitting diodes (LEDs). Previous research on photon upconversion mainly focused on upconversion nanoparticles (by nonlinear anti-Stokes emission) [2]. This kind of upconversion is limited by the materials and has a narrow band of excitation/emission wavelength. In contrast, our optical upconverter can be excited by a wide range of light wavelengths: from visible to infrared light. The emission wavelength can reach blue or even shorter wavelengths which are determined by the LED's emission.

Summary of Research:

The broadband optical upconverter is made by fabricating silicon (Si) PVs and gallium nitride (GaN) LEDs separately and then integrating them together.

To fabricate Si PVs, we start from n-type doped SOI wafers and utilize phosphosilicate glass to dope the top layer, creating a vertical PN junction. The PVs' contacts and interconnect are Pt/Ti and are deposited through AJA sputtering tool. The PVs are isolated by inductively coupled plasma (ICP) etching (Cobra ICP etcher).

To fabricate GaN LEDs, we start from GaN heterostructure wafers (from a commercial vendor). The n-contacts and p-contacts are Au/Pd and Ti/Au respectively, which are deposited through e-beam evaporation. The LEDs are outlined by ICP dry etch via PT770 etcher.

After the PVs and LEDs are fabricated on their native substrates, we integrate them together through a transfer method developed by our group. We spin ~ 6 µm PMMA onto the LEDs as the protection layer. By using a thermoplastic polymer (polypropylene carbonate), we bond the LED substrate to a sapphire carrier wafer through Hot Press. Afterward, the LEDs' native substrate is removed by laser lift-off. In the end, the LEDs are aligned and transferred to the PV substrate via ABM contact aligner alignment and Hot Press bonding. The carrier wafer is removed through thermal slide. The polymer residue is cleaned in acetone.

Our upconverters are powered by long-wavelength light and emit short-wavelength light. The optical energy is firstly converted into electrical energy and then converted back to optical energy, which is an optical-electrical-optical (O-E-O) process. Si PVs carry out the optical-electrical conversion. Si's narrow bandgap (~1.1eV) enables a broad range of excitation photon energies. GaN LED performs the electrical-optical conversion. The efficiency of our upconverter is determined by the product of two efficiencies: Si PV's conversion efficiency (~20%) and GaN LED's light-emitting efficiency (~2%). Therefore, overall power efficiency can reach ~ 0.4%, which is comparable to the upconversion nanoparticles (~0.01%-1%) [3].

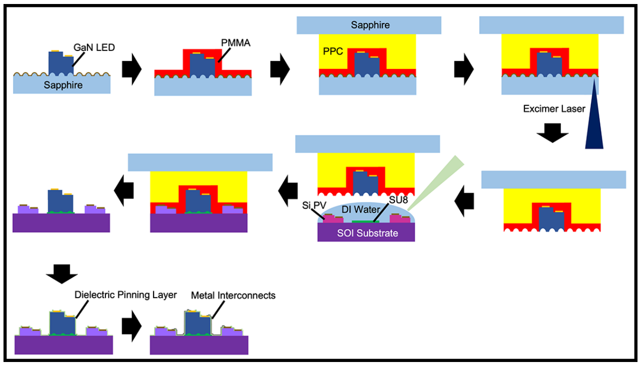

Figure 1: Schematic illustration of the upconverter integration process.

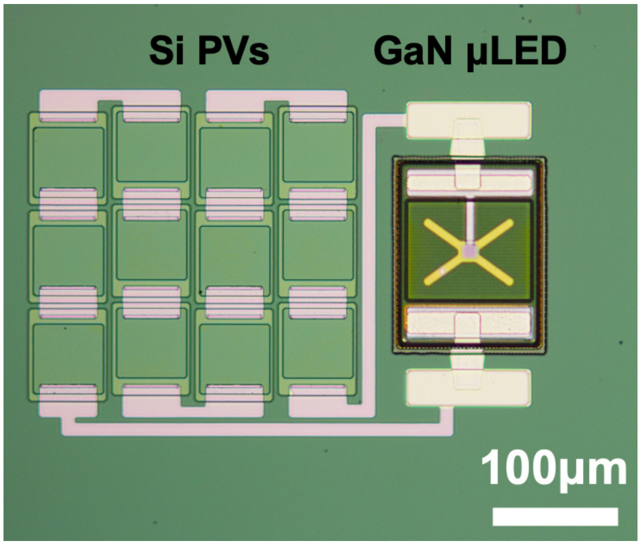

Figure 2: Optical image of an upconverter.

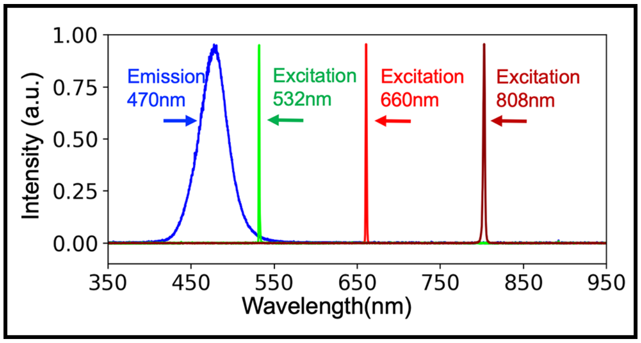

Figure 3: Spectra of the excitation source (532 nm, 660 nm, and 808 nm laser) and the upconverter's emission with a peak at 470 nm.

Conclusions and Future Steps:

Here we present a platform that enables microscale broadband optical upconverters made by heterogeneous integration of Si based PVs and III-V materials-based LEDs. This heterogeneous integration technique allows the fabrication of thousands of optical upconverters in parallel per wafer. The efficiency of the upconverter is ~ 0.4%, which is comparable to the best upconversion nanoparticles. Our next step is to make devices with more sophisticated functions based on this platform. It will be integrating CMOS circuits with III-V materials based optical devices.

References:

[1] Zhou, B., Shi, B., Jin, D. and Liu, X. Controlling upconversion nanocrystals for emerging applications. Nat. Nanotechnol. 10, 924-936 (2015).

[2] Auzel, F. Upconversion and anti-Stokes processes with f and d ions in solids. Chem. Rev. 104, 139-173 (2004).

[3] Algar, W. R. et al. Photoluminescent Nanoparticles for Chemical and Biological Analysis and Imaging. Chem. Rev. 121, 9243-9358 (2021).