MicroLED/LED Electro-optical Integration Techniques for Non-Display Applications

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Columbia University…where are we?
Columbia University’s EE department
30 faculty, and (normally) ~100 undergrads,
~160 Ph.D. students, ~350 MS students
This year we are just shy of 900 students
MicroLEDs are an exciting new technology

LED displays represent the brightest, most efficient structured light sources possible with any known technology

- 20-50M nits (visible)
- High power conversion efficiency
- Emissive display
- No filters or polarization management needed (2-5x)

Great (at least on paper) for displays, we should also consider them for non-display applications
Just how much luminance?

![Graph showing luminance comparison]

- Candle
- LCD/LED TV
- LCD/LED Phone
- Cloudy Sky
- Clear Sky
- Fluorescent lamp
- microLED
- Direct sun
What can we do with them?

• Displays
  – DV
  – Indirect view


• Non-display

Kumar V, Kymissis I. MicroLED/LED electro-optical integration techniques for non-display applications. Applied Physics Reviews. 2023 Jun 1;10(2).
A few (non-display) applications for microLEDs
Superresolution microscopy using structured light

- Structured light allows for significant improvement in the images captured by optical systems
- Even a simple multiple exposure pattern can be used (e.g. alternating bars)

(b) Poher et al., Optics Express 15, 11196 (2007)
Where might we do this (where LEDs offer an advantage)?


Collaboration with UC Boulder
Layout for superresolution bar light source

2 mm x 15 μm emitters
100 microstripes
SIM lightsource
SRM using uLED

- With a few patterns SRM is possible in a lightweight/portable format

Photolithography

• The high intensity allows for structured maskless exposure
• Shorter wavelengths are available than ever
• The high speed also (possibly) allows for better control

Visible light communication

- LEDs allow for straightforward integration (esp for free-space)
- MicroLEDs permit faster switching than “bulk” LED structures

Chen et al., ACS Photonics 7, 2228 (2020).
Photostimulation

- Optogenetics + other photostimulation approaches

(b) Wu et al., Neuron 88, 1136 (2015).
What are some of the material/format issues for non-display microLEDs?
MicroLEDs (all LEDs) need a backplane to have reasonable resolution

- It’s well established that a backplane is needed to drive microLEDs at anywhere close to peak efficiency/luminance/duty cycle/etc.

\[
\Delta V_{max} = \sum_{x=0}^{m} x \cdot I_{px} \cdot R_{cell}
\]

\[
\Delta V_{max} = \frac{m(1 + m)}{2} \cdot I_{px} \cdot R_{cell}
\]

\[
\Delta V_{max} \approx \frac{m^2}{2} \cdot I_{px} \cdot R_{cell}
\]
An active matrix is complicated!

Usually (!) we can get away with a passive matrix

- For low resolution… more than adequate
- Requires some consideration, since we have to trench the LEDs (creating mesas)

Beherman, thesis
Isolation/Efficiency/Current Density
How small is too small?

- There is some sidewall recombination that is seen in both monolithic and chiplet devices
- There is illumination inhomogeneity associated with damage, waveguiding, and sidewall recombination

https://doi.org/10.1016/j.jcrysgro.2004.04.085
Sidewall recombination is one challenge.


Current density is another

Current density calculated by pGaN contact area for consistency (modeled)

Yield is a third ...

Photoluminescence
Cathodoluminescence
Electroluminescence

Recombination is not always bad (?!)

- For OLC, recombination can help offer a greater apparent speed
- Smaller mesas as well as higher current density can deliver this

Light extraction
Conventional extraction (e.g. LED lighting)

- PSS and roughening can extract the light well
- This occurs through scattering, and loses the positional information usually required

Near-field optics

- Near-field optics allow for better coupling to optical system without losing the spatial structure

Microlenses

- Many options for integration (e.g. reflow processes)

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More microlenses + apertures

Beherman
Using flat optics

- Flat optics (e.g. photonic crystals) can also deliver superior coupling without scattering

Wavelength control
To first order, most microLEDs are monochrome

- You get what’s cooked into the wafer, right?

LEDs today are better than ever

- New growth processes have overcome many of the challenges of the past

LEDs can also be grown and/or bonded together

- Most non-display applications need only one wavelength…but sometimes more than one is strategic (e.g. WDM)
- Bonding, nanowires, and downconversion can deliver this

Fanlu Zhang et al, High-speed multiwavelength InGaAs/InP quantum well nanowire array micro-LEDs for next generation optical communications, Opto-Electronic Science (2023)
How about chiplets for non-display?
The brain is very tightly vasoregulated; IOS can measure activity.

In a seizure, there is a typical pattern of blood flow: deoxygenation, response, re-perfusion.

The spatial resolution of this response is better than 100um.

Collaboration with Hongtao Ma and Theodore Schwartz, Cornell Medical.
An implantable monitor…

• Would allow for persistent monitoring
• Higher resolution than electrical measurement
• Could measure more than just spike activity

• But…needs to fit under the skull
Using uLED as both emitter and detector
QD raw spectra

- Amber QD
- Red QD
- Green QD

Normalized Light Intensity vs. Wavelength (nm)
Multiple wavelength operation

(a) Photo of a setup for multiple wavelength operation.
(b) Close-up of a specific components.
(c) Graph showing light emission across different wavelengths with color-coded coatings.
(d) Graph depicting LFP and ORIS data over time, with a 2 min interval indicated.
Arthritis mapping using LEDs

Andreas Heilscher, Theanne Schiros (FIT), Youngwan Kim, Barbara Tripper (UTA), Amy Sperber (FIT), Anastasia Edwards (FIT)
Reconstruction of diffuse data
Measurement of diabetic foot

SFA. The mid SFA and PA were treated with a self-expanding stent. Patient D received angioplasty on her/his SFA with drug-coated balloon. The differences in the hemodynamic responses observed before and after operation are clearly observable for both patients.

Figure 5-10 Hemodynamic responses before and after interventional procedures to the 60 mmHg occlusion on two different locations of feet (a) Toe, (b) Heel, and (c) Dorsum of foot), measured by the We-FOIS holding three wavelengths of 770 nm, 850 nm, and 940 nm. For patient C, the We-FOIS also assessed the dorsum of the feet (Figure 5-10 (c)) and we applied the SRS code to determine the chromophore concentration of HbO₂ and Hb for venous...
First measurement in breast cancer patient during 20 sec breath hold (@2cm distance)

- Δ[Hb]% steadily increases in tumor over course of the breath hold.
- Upon resuming breathing the respiratory cycle is seen in the movie.

How Does it Work?    Monitor Breast Hemodynamics!
Use of diffuse imaging to map blood vessels

- Blood vessel regrowth and oxygenation are monitors for the post-surgical healing
Conclusions

• LEDs offer an unmatched performance in generating light
• There are a number of material / device / drive / process issues that could stand additional attention, especially for non-display applications
• There is a co-optimization of size and efficiency at the pixel level for each display type, in addition to significant opportunity for optical emission control
• Both small and large microLED system formats offer opportunities in the non-display space
• Using the LEDs as both emitters and detectors offers some additional opportunities
For more information

- Kumar V, Kymissis I. MicroLED/LED electro-optical integration techniques for non-display applications. Applied Physics Reviews. 2023 Jun 1;10(2).
The team

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