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A Study of n-side up Thin Film AlGaInP Red Vertical LEDs with Copper/Invar/Copper Metal Substrates

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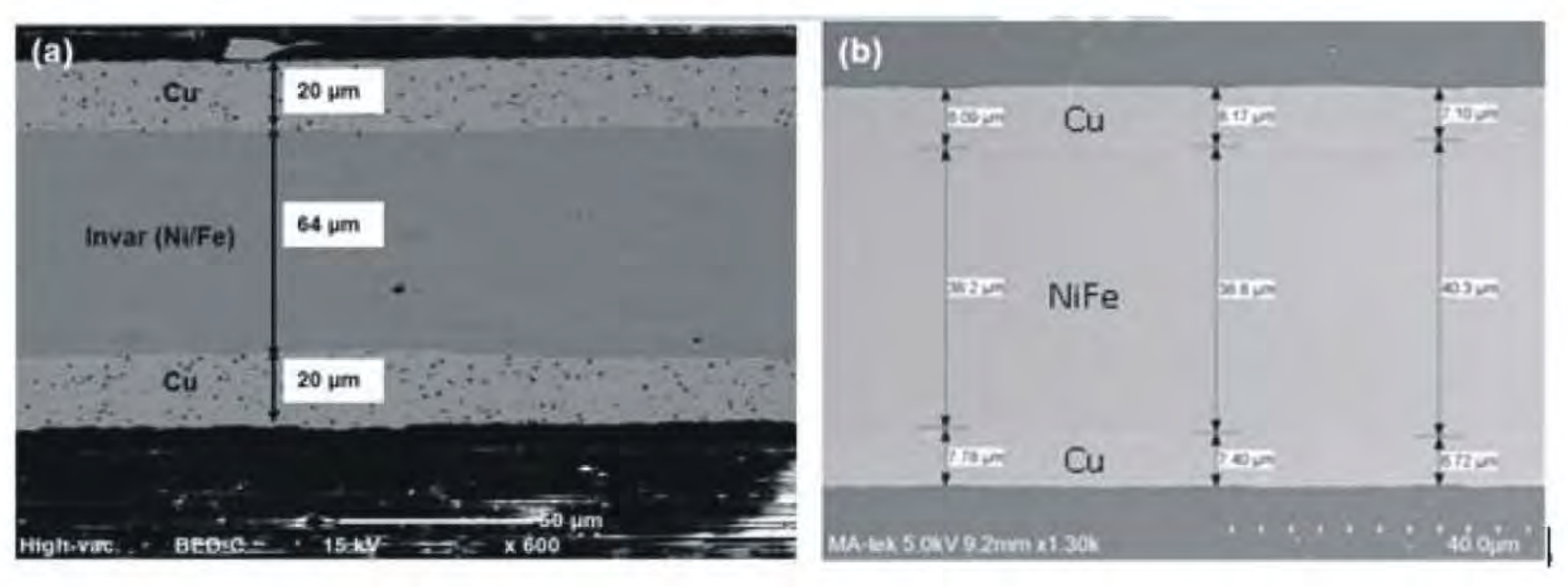
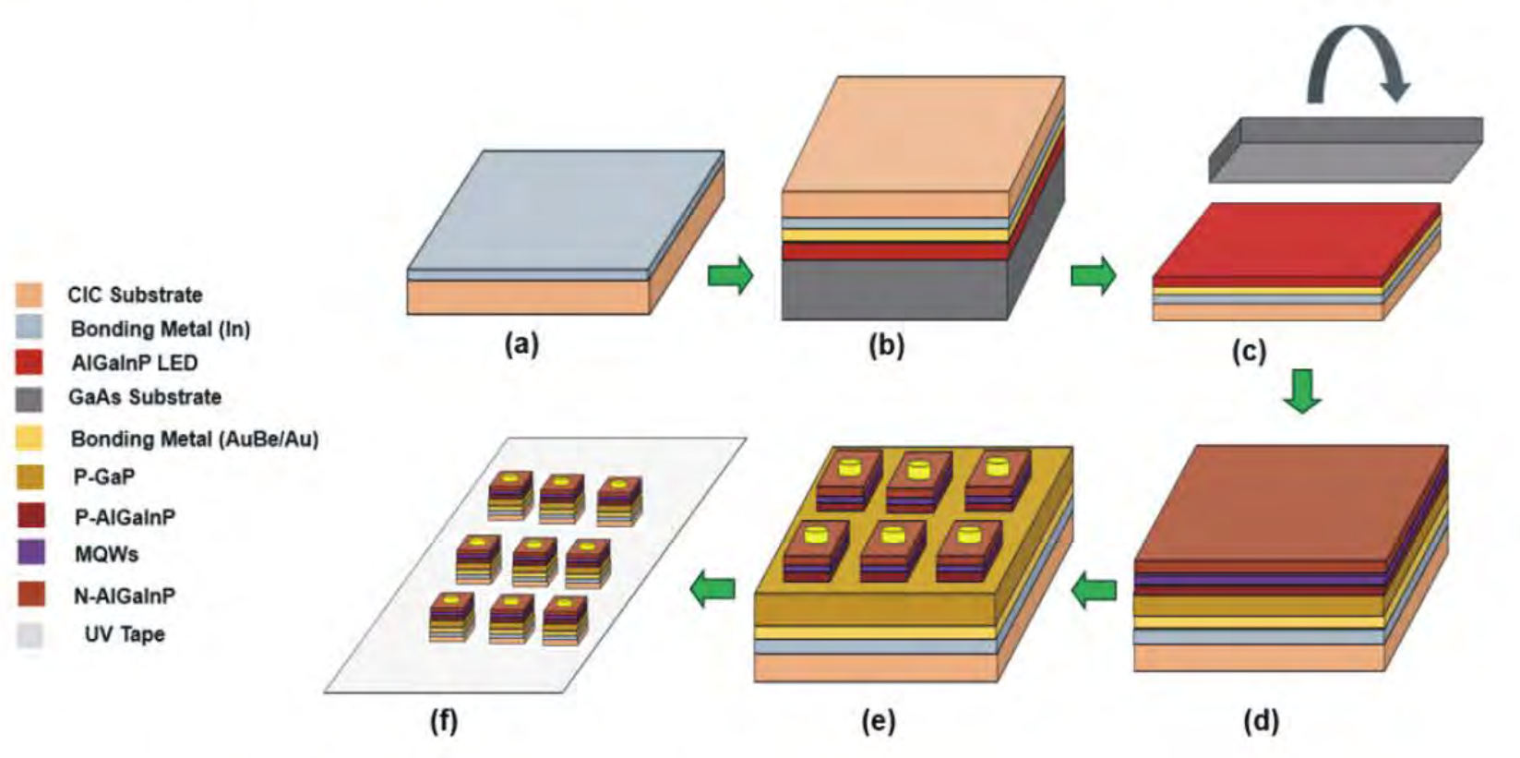
Abstract

In this study, n-side up, thin-epilayer, AlGaInP based vertical light-emitting-diodes with a copper-invar-copper (CIC) composite metal substrate was obtained by wafer bonding techniques and epilayer transferring technologies. The structure of the CIC substrate is a sandwich structure and consists of a top Cu layer, a middle Invar layer, and a bottom Cu layer. The invar layer consists of Fe and Ni at a ratio of 70% to 30% and the thermal conductivity of CIC is 195.6 W/m-K. The high performances of the packaged LEDs are obtained. They present a low red shift phenomenon and a high output power. The small LEDs provide a larger current density under the same voltage and present smaller forward voltage, a low red-shift phenomenon and low output power density. Larger LEDs exhibit maximum EQE at lower current density as compared to smaller LEDs. The CIC substrate could be extended to fabricate high-efficiency thin film LEDs with conventional vertical electrodes. After the development and fabrication of n-side up thin-film AlGaInP LED chips on the copper-based composite substrate could be diced by wet etching instead of laser or saw dicing.

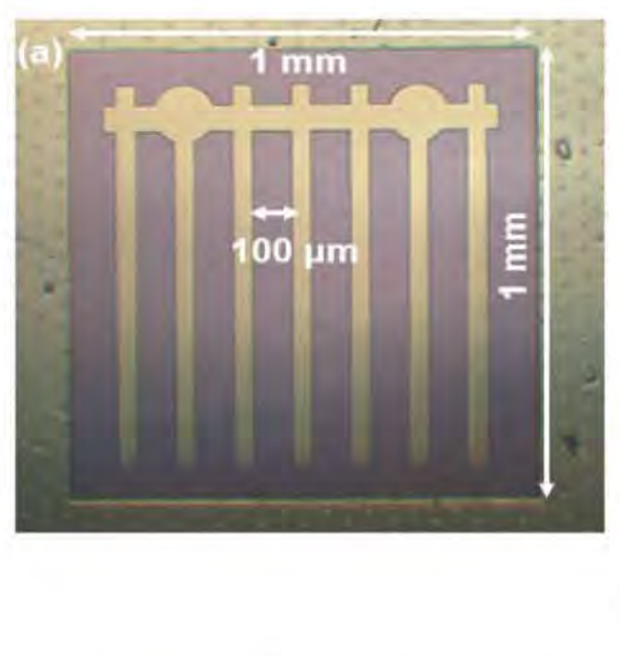
Research Focus and Results



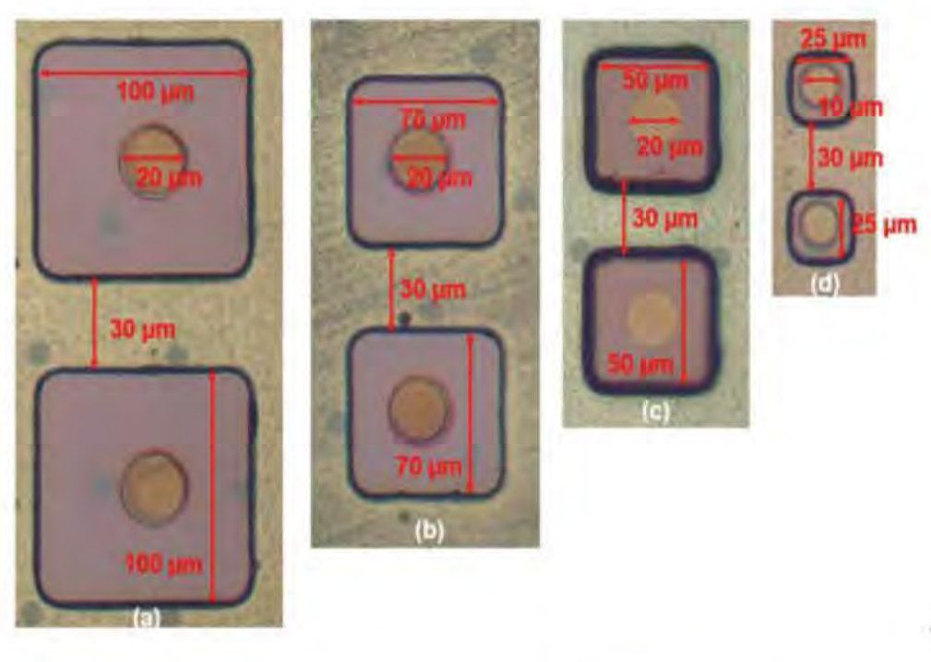
SEM cross section image; (a) 100 μm thick CIC substrate (b) 50 μm CIC substrate



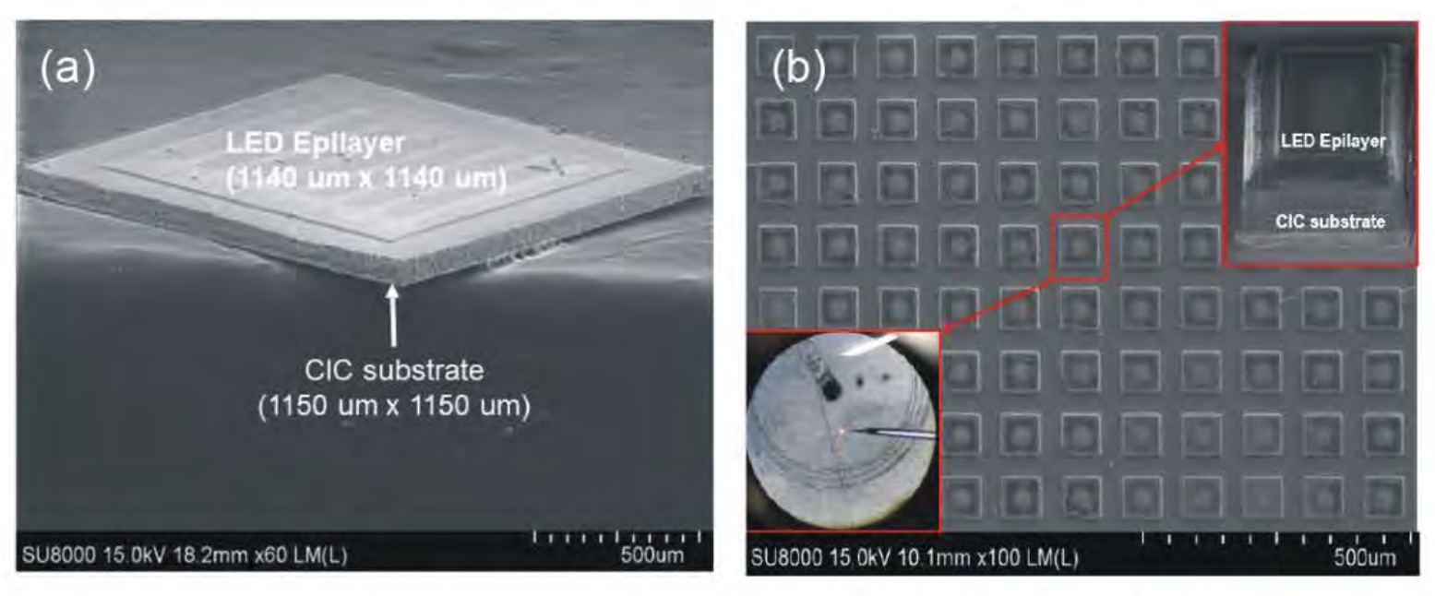
Process flow of red *V*-LEDs on CIC metal substrate; (a) Deposition of metal on CIC for bonding, (b) Metal/CIC bonded with LED epilayer/GaAs, (c) Removing GaAs substrate, (d) LED structure on CIC after removing of GaAs substrate, (e) Fabricated LED on CIC, and (f) Diced V-LEDs/CIC on tape.



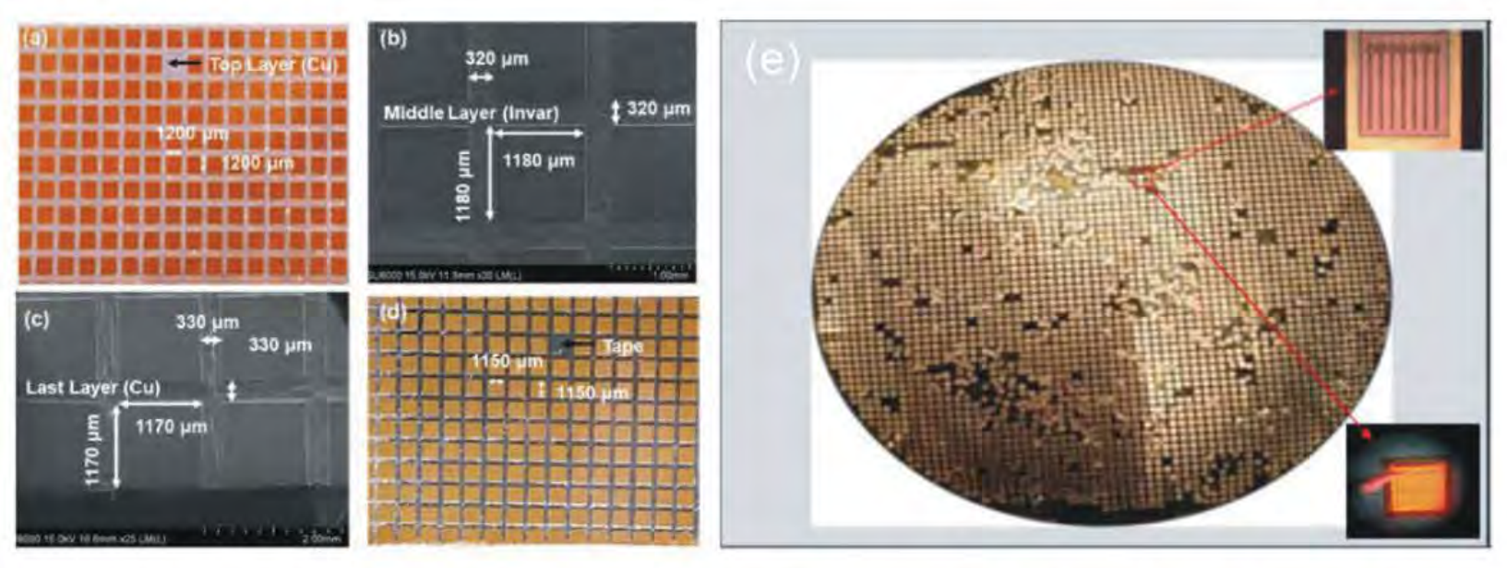
OM image of N-side up thin-film epilayer, AlGaInP based vertical LED/CIC (Power chip; emitting area: 1 mm × 1 mm).



Different chip sizes of LEDs/CIC after the whole process by optical microscope (OM) Image (a) LED(100), (b) LED(70), (c) LED(50), and (d) LED(25).



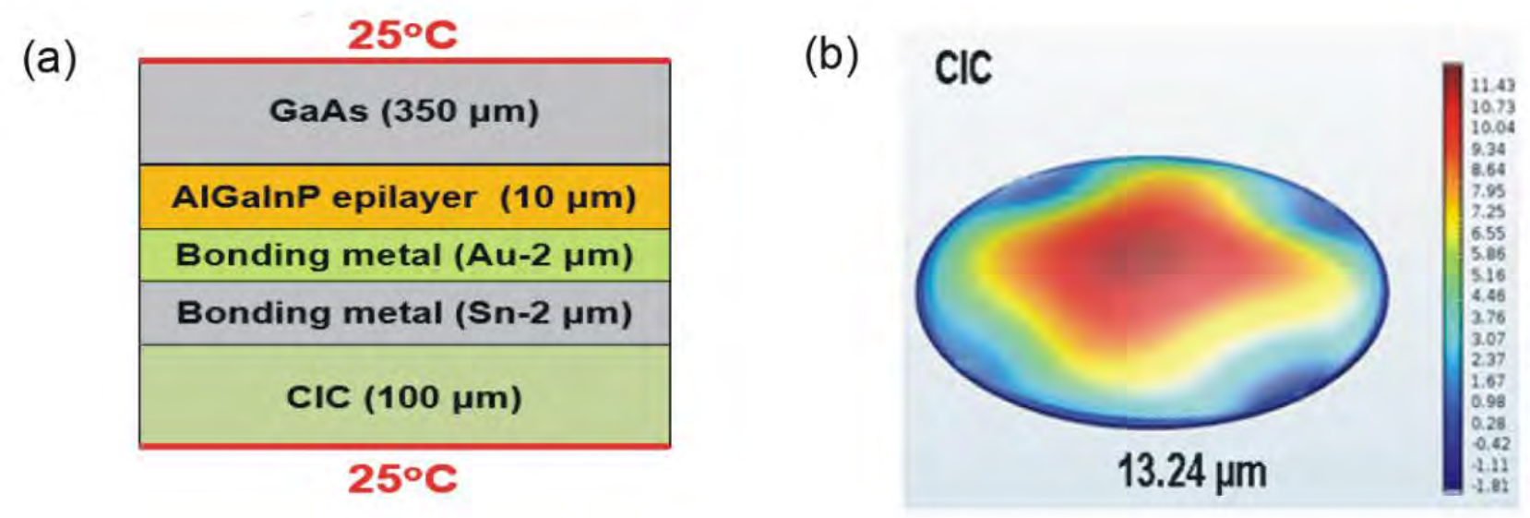
(a) Cross section SEM image of typical single chip with LED (b) Thin film AlGaInP *μ*-LED on CIC measured by SEM. The insets show the typical single chip after dicing and lightening picture of the diced *μ*-LED/CIC.



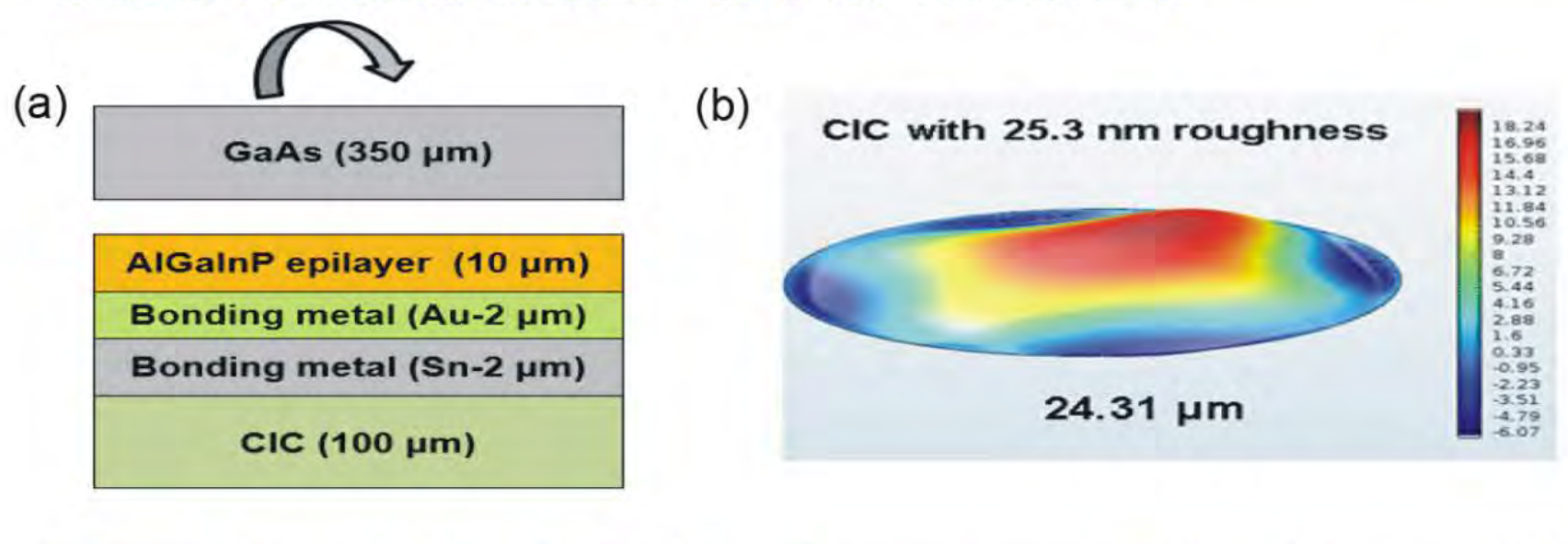
Chip dimensions before and after wet etching from the back side of the CIC for dicing: (a) OM image of the chip pattern before the etching process; (b) SEM image of the middle layer (Invar); (c) SEM image of the last layer (Cu); (d) OM image of the diced chip.(e) Diced LED/CIC chips from the back side of the CIC by the wet etching process.

	CIC	GaAs	AlGaInP
CTE (K^{-1})	6.1×10^{-6}	5.7×10^{-6}	5×10^{-6}
Cp (J/kg-K)	425	550	410
Density (kg/m^3)	8260	5316	4550
Thermal conductivity (W/m-K)	196	33	-
Young's modulus (Pa)	128×10^{-9}	85.9×10^{-9}	103×10^{9}
Poisson's ratio (1)	0.285	0.31	0.31

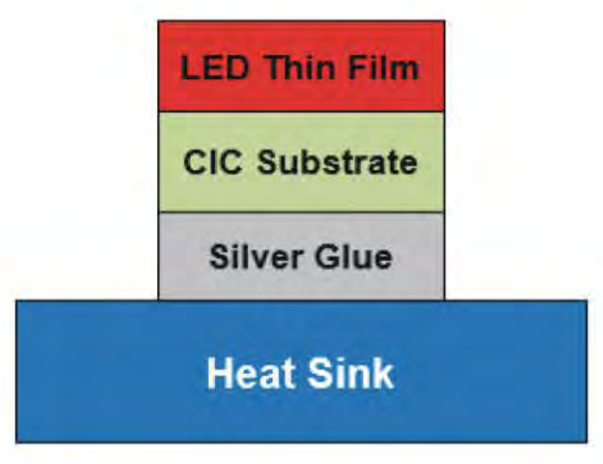
Simulated Material Properties



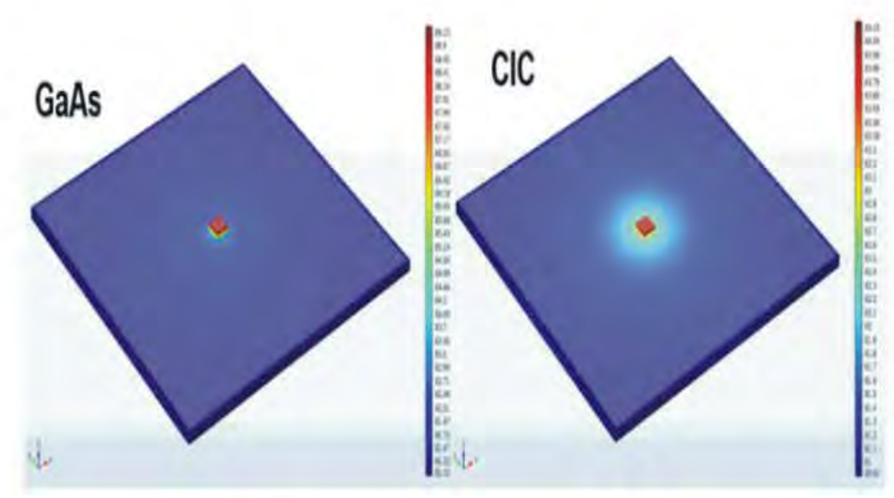
(a)Simulation model of wafer-bonding from 300°C to 25°C and (b) bending simulation of different substrates bonded with GaAs substrate



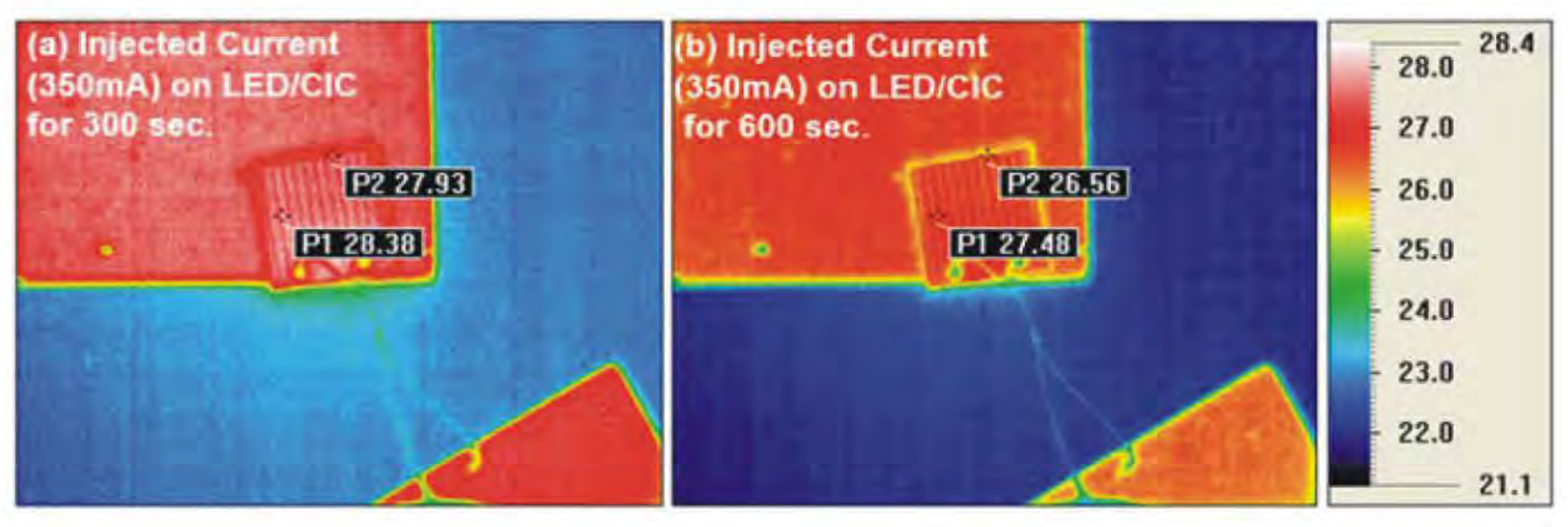
(a)Simulation model of wafer-bonding after removing the GaAs substrate and (b) bending of different substrates after removing the GaAs substrate



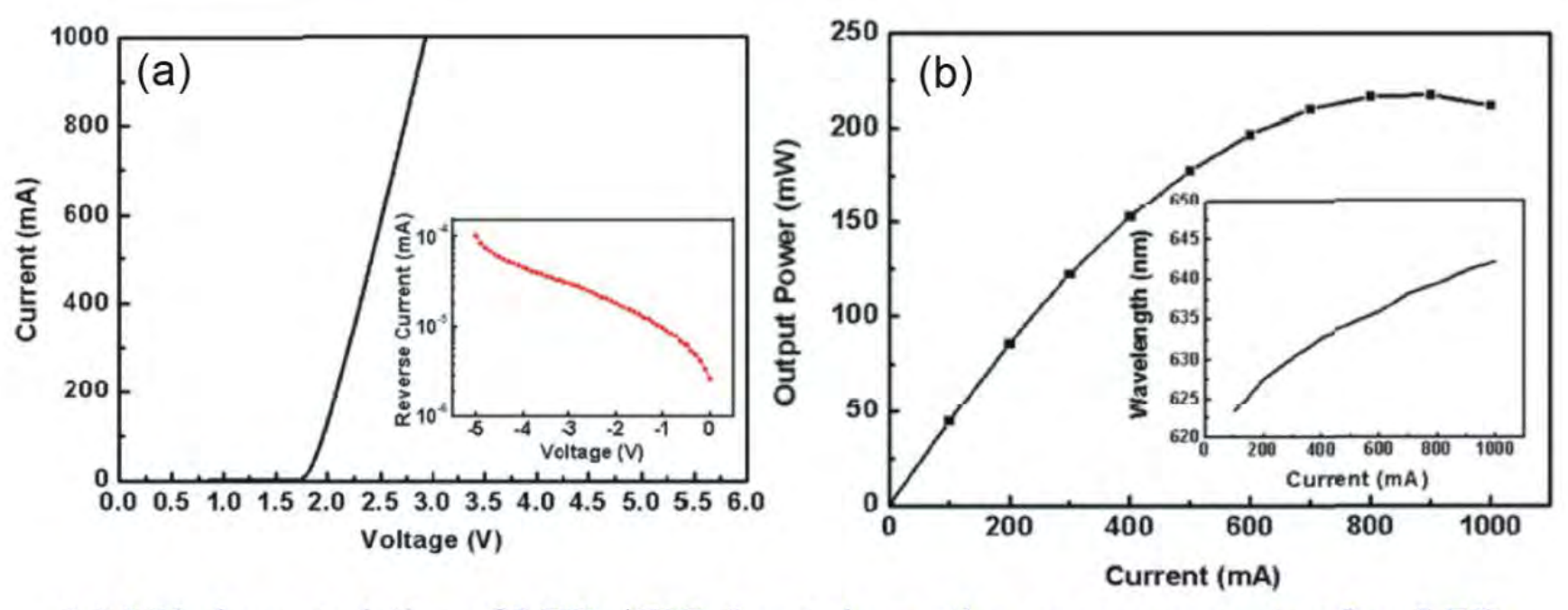
Simulation model: LED thermal conduction condition



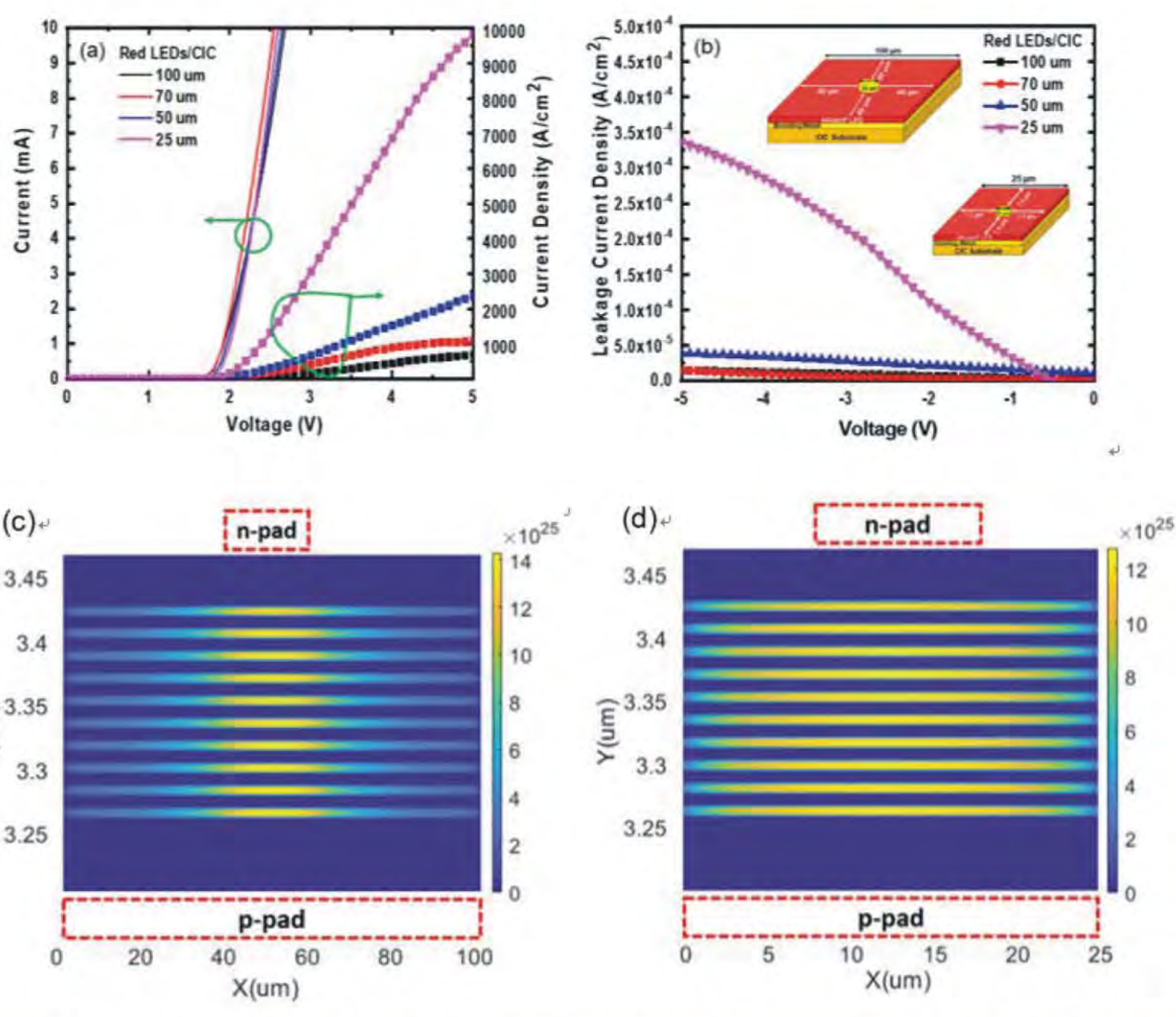
Simulation Result: Temperature distribution for two different bonding substrate



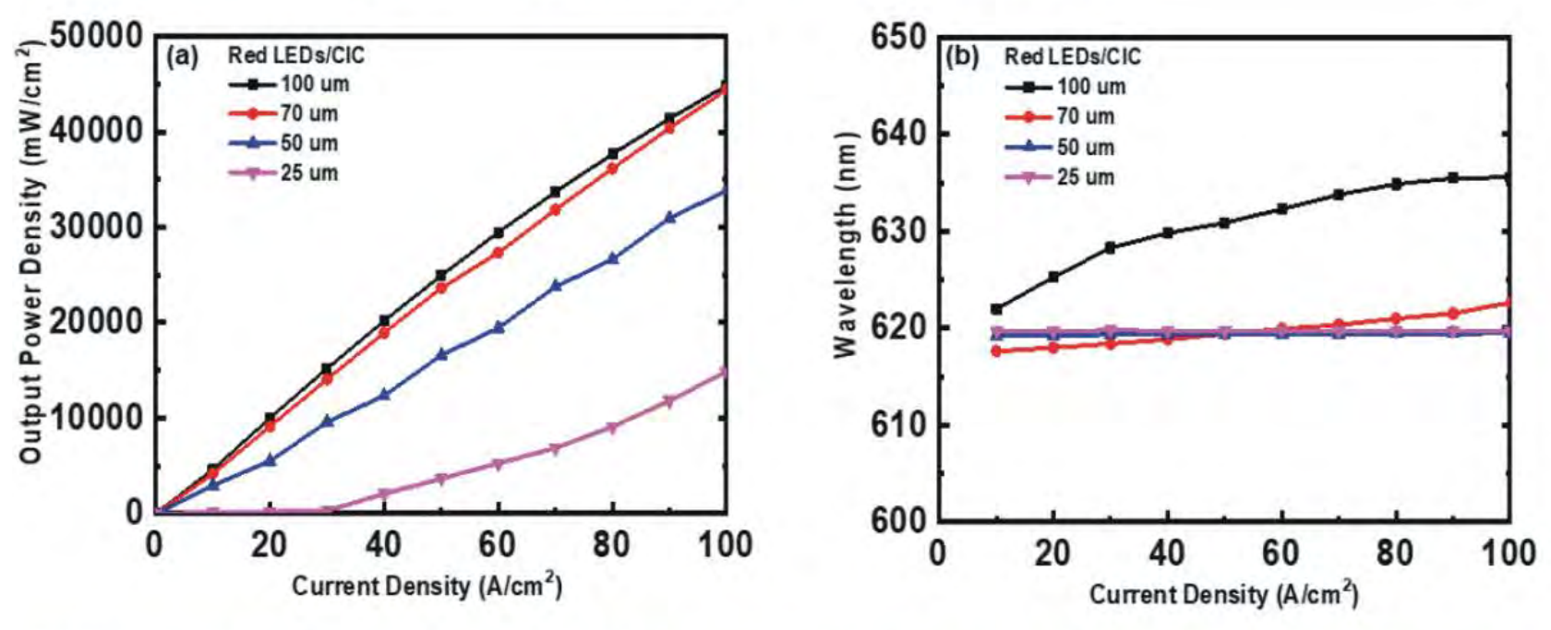
The distribution of temperature throughout the surface of the LED/CIC (injection current 350 mA) for 300 seconds and 600 seconds



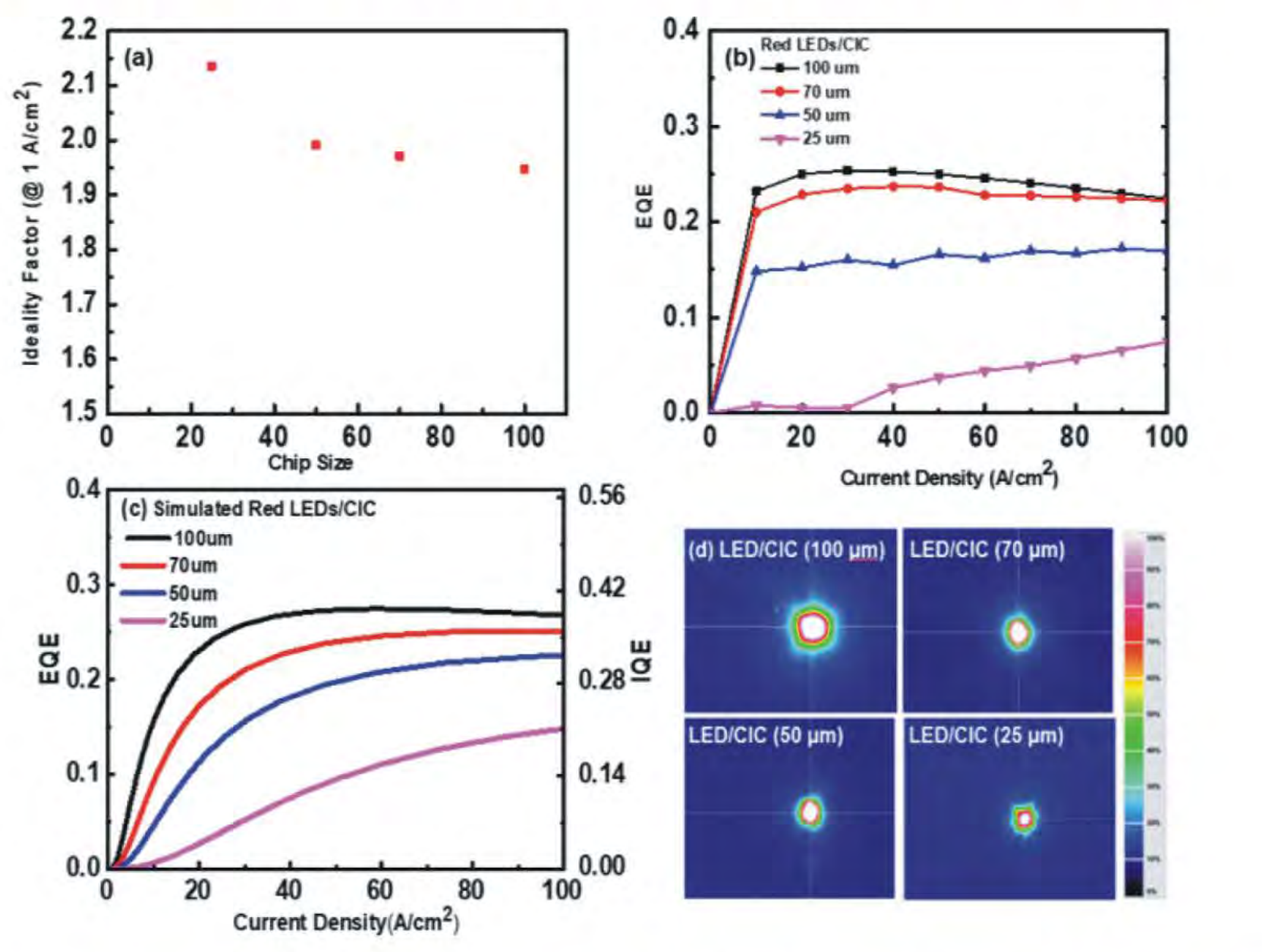
(a) I-V characteristics of LEDs/CIC. Inset shows the reverse currents of an LED chip as a function of voltage (b) Output power of LEDs/CIC as a function of current. Inset shows the wavelength-current characteristics



(a) I-V and J-V curves for LEDs with different chip sizes and (b) leakage current density as a function of reverse voltage. 2D simulated radiative recombination distribution in MQWs for (c) LED(100) and (d) LED(25).



(a) Output power density and (b) wavelength (λp) as a function of current density



(a) Ideality factor of LEDs/CIC at 1A/c m² as a function of chip sizes, (b) Calculated EQE curve as a function of current density of *μ*-LEDs/CIC, (c) Simulated EQE and IQE curves of the LEDs/CIC, and (d) Emission images of LED(100), LED(70), LED(50), and LED(25).

Publications:

1. **Shreekant Sinha**, Fu-Gow Tarntair, Cheng-Han Ho, Yuh-Renn Wu, Ray-Hua Horng, "Investigation of electrical and optical properties of AlGaInP red vertical micro-light-emitting diodes with Cu/Invar/Cu," *IEEE Transactions on Electron Devices*, vol. 68, no. 6, pp. 2818-2822, June 2021.
2. R. H. Horng, **Shreekant Sinha**, F. G. Tarntair, H. A. Feng, C. W. Tu, "Dicing of composite substrate for thin-film AlGaInP power LEDs by wet etching," *Scientific Reports,* 11, 10914 (2021), May 2021,
3. **Shreekant Sinha**, H. A. Feng, C. Y. Chung, C. W. Tu, R. H. Horng, "Comparison of Properties of Thin Film AlGaInP LEDs with Composite Metal and Si Substrates," *ECS J. Solid State Sci. Technol.,* vol. 9, no. 1, 015015, Nov. 2019, R. H. Horng,
4. R. H. Horng, **Shreekant Sinha**, C. P. Lee, H. A. Feng, C. Y. Chung, and C. W. Tu, "Composite metal substrate for thin film AlGaInP LED applications," *Optics Express*, vol. 27, pp. A397-A403, Apr. 2019.

Conclusions

(1) This research has successfully used wafer bonding technology to transfer the AlGaInP epitaxial film to the CIC and transferring yield rate can reach more than 95%.
(2) Thin film LEDs on CIC not only presented normal electrical properties, but also presented a high performance of optical properties.
(3) Dicing of LED/CIC chips was obtained by the wet etching process.
(4) CIC substrate can be diced by the wet etching without any physical damage or epilayer cracking, indicating that the wet etching can be used in place of saw or laser dicing and extended for thin film micro LED applications.
(5) Small-size LEDs/CIC provide a larger current density under the same voltage and present a low red-shift phenomenon and low output power density. In addition, smaller LEDs exhibit minimum EQE at a lower current density as compared to larger LEDs due to the larger sidewall to surface ratio. Last, the EQEs of small thin-film V-*μ*LED chips have a much stronger SRH recombination at the low-density region.
(6) Due to its low cost, thickness, high thermal conductivity and ease of dicing, CIC substrate has the potential to replace the Si and CuW substrate to improve the performance of AlGaInP thin film LEDs and applications.

Acknowledgement

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