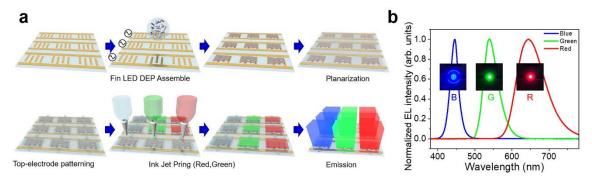
Supplementary Information for

Development of Fin-LEDs for Next-generation Inorganic Displays using Face-selective Dielectrophoretic Assembly

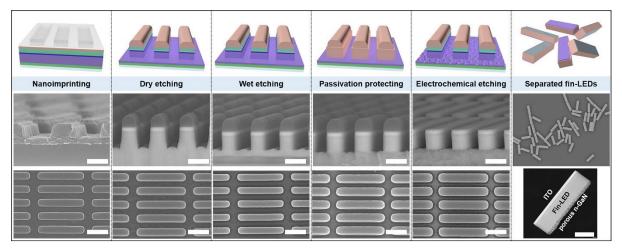
SeungJe Lee¹‡, Yun Jae Eo¹‡, Minji Ko¹, Soomin Ahn¹, Selim Yun¹, Hyeng Jin Kim¹, Eunha Hong¹, Yuna Kwon¹, Huiyeong Kang¹, Yong Jae Lee¹, Gang Yeol Yoo², Keyong Nam Lee¹, Jae Kyu Song³, Jong Kyu Kim⁴, Hyun Min Cho², Young Rag Do¹*

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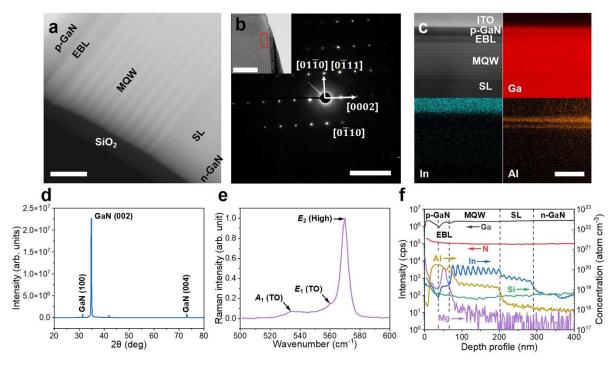


Supplementary Fig. 1 | Schematic of implementing a full-color fin-LED Displaya Schematic of full-color fin-LED display. b Fin-LED color conversion RGB EL spectrum (Blue: fin-LED, Green: fin-LED@InP QDs color film, Red: fin LED@R6832 phosphor color film.



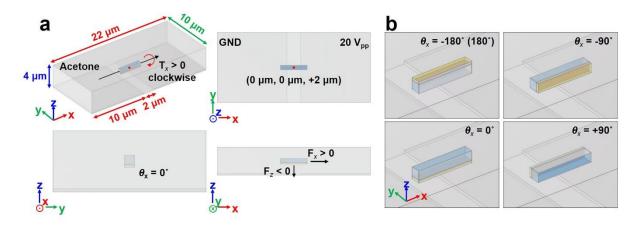
Supplementary Fig. 2 | Schematic diagram of fin-LED fabrication process

Electron microscopy images of each step of fabrication process of individually separated fin-LED. All scale bars represent 1 μ m.



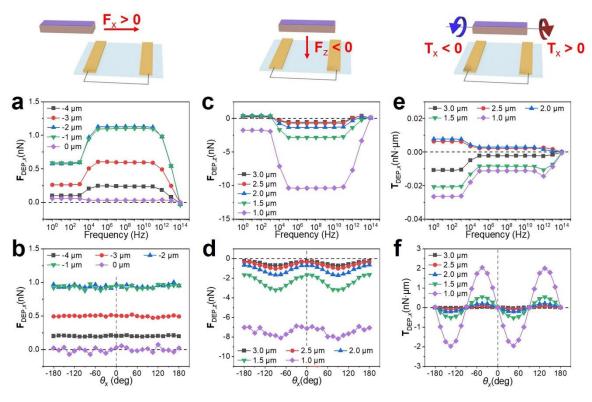
Supplementary Fig. 3 | Additional analysis data for individually separated fin-LED

a High-angle annular dark-field (HAADF)-STEM image of ITO/p-GaN/MQW/n-GaN@SiO₂ structured fin-LED. **b** Selected area electron diffraction (SAED) patterns of MQW of fin-LED. (Insect TEM image of fin-LED) **c** Energy-dispersive X-ray spectroscopy (EDX) images of fin-LED. **d** X-ray diffraction (XRD) spectrum of fin-LED. **e** Raman spectrum of fin-LED. **f** Dynamic-secondary ion mass spectroscopy (SIMS) depth profiles of fin-LED. EBL, electron blocking layer; MQW, multiple quantum well; SL, superlattice.



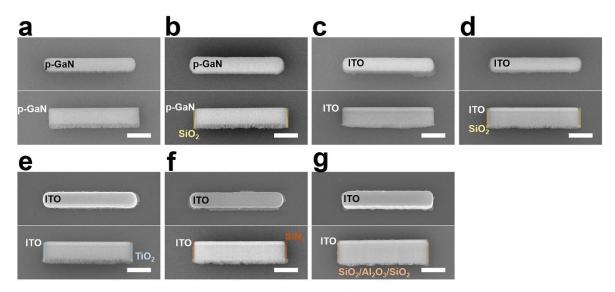
Supplementary Fig. 4 | Schematic of 3D model for finite element simulation (FEM)

a A pair of 10 μ m × 10 μ m electrodes were placed on the bottom with a 2 μ m gap on the entire domain size of 22 μ m × 10 μ m × 4 μ m. The center coordinates of a GaN-based light-emitting diode (LED) were arranged to be (0 μ m, 0 μ m, +2 μ m). The remaining area except for the electrodes and LED was composed of solvent (acetone). **b** Schematic diagram according to x-axis rotation angle of the LED. It was set to 0° when the n-GaN was facing upward. The n- and p-GaN, ITO, and the shell layer on the side of the LED (SiO₂) are expressed in blue, red, yellow, and white, respectively.



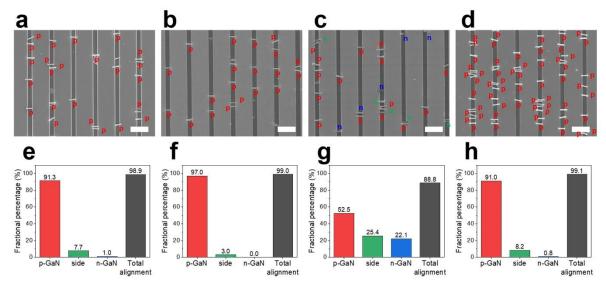
Supplementary Fig. 5 | FEM simulation results of ITO/fin-LED@SiO2 LED

a,**b** The x-axis dielectrophoretic (DEP) force as a function of frequency of the LED with an x-angle of 0° and as a function of x-angle of the LED with a frequency of 10 kHz when the central coordinates of LED changed from ($-4 \mu m$, 0 μm , $+2 \mu m$) to (0 μm , 0 μm , $+2 \mu m$). **c**,**d** The z-axis DEP force as a function of frequency of the LED with an x-angle of 0° and as a function of x-angle of the LED with an x-angle of 0° and as a function of x-angle of the LED with a frequency of 10 kHz when the central coordinates of LED changed from (0 μm , 0 μm , $+3 \mu m$) to (0 μm , 0 μm , $+1 \mu m$). **e**,**f** The x-axis DEP torque as a function of frequency of the LED with an x-angle of 0° and as a function of x-angle of the LED with an x-angle of 0° and as a function of x-angle of the LED with a x-angle of 0° and as a function of x-angle of the LED with an x-angle of 0° and as a function of x-angle of the LED with a x-angle of 0° and as a function of x-angle of the LED with a x-angle of 0° and as a function of x-angle of the LED with a x-angle of 0° and as a function of x-angle of the LED with a frequency of 10 kHz when the central coordinates of LED changed from (0 μm , 0 μm , $+3 \mu m$) to (0 μm , 0 μm , $+1 \mu m$).

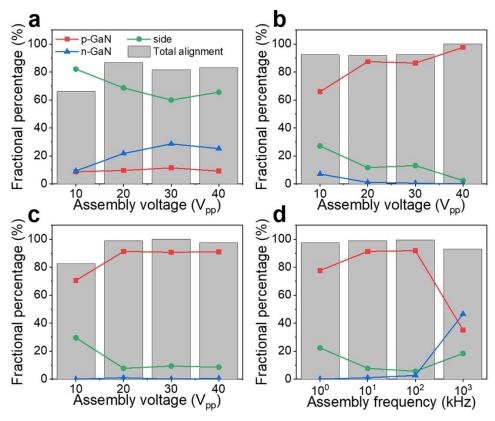


Supplementary Fig. 6 | SEM images of fin-LED with different structures

The upper images are the top view of the fin-LEDs and the lower images are the cross-sectional view of the fin-LEDs obtained in backscattered electron (BSE) mode. **a** fin-LED. **b** fin-LED@SiO₂. **c** ITO/fin-LED@SiO₂. **d** ITO/fin-LED@SiO₂. **e** ITO/fin-LED@TiO₂. **f** ITO/fin-LED@SiN_x. **g** ITO/fin-LED@SiO₂/Al₂O₃/SiO₂. All scale bars represent 1 µm.



Supplementary Fig. 7 | Self-assembly results of different structured fin-LED by DEP force **a**–d SEM image of ITO/fin-LED@SiO₂, ITO/fin-LED@SiN_x, ITO/fin-LED@TiO₂, and ITO/fin-LED@SiO₂/Al₂O₃/SiO₂ structures. To align the fin-LEDs of all structures, a sinusoidal function with a voltage of 20 V_{pp} and a frequency of 10 kHz was applied to the electrodes. To indicate the contact surface between the fin-LEDs and electrodes, different colored letters were marked on the individual LEDs: red p, p-GaN contact; blue n, n-GaN contact; green s, side contact. All scale bars represent 10 µm. **e**–**h** Fractional ratio of different contact of ITO/fin-LED@SiO₂, ITO/fin-LED@SiN_x, ITO/fin-LED@TiO₂, and ITO/fin-LED@SiO₂/Al₂O₃/SiO₂ structures. All scale bars represent 10 µm.



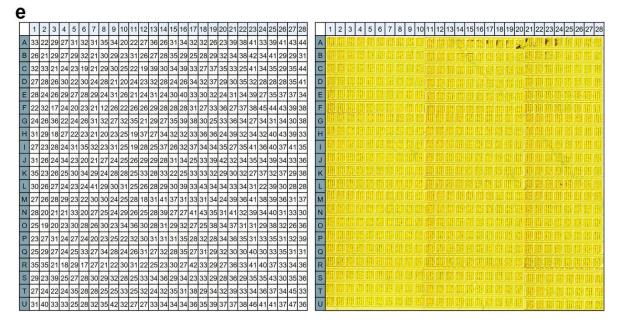
Supplementary Fig. 8 | Fractional ratio of different ITO/fin-LED@SiO2 with solvent

a–**c** Fractional ratio in hexane, isopropyl alcohol (IPA) and acetone depending on the voltage with an applied frequency of 10 kHz (sinusoidal wave function). **d** The ratio in acetone depending on the frequency with an applied voltage of 20 V_{pp} . All legends in the graphs are identical to those expressed in **a**.

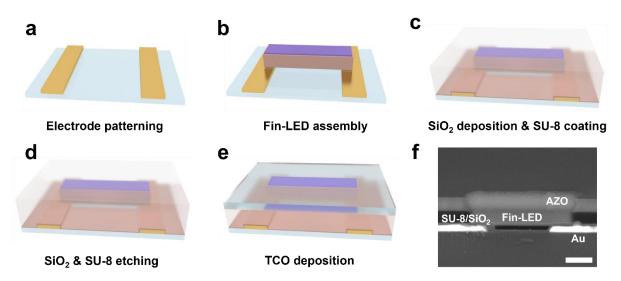
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Supplementary Fig. 9 | Optical microscope image of five fin-LED array devices with 588 subpixels a Panel-1, mean: 30.47, standard deviation (σ): 4.16. b Panel-2, mean: 31.06, σ : 6.40. c Panel-3, mean: 31.27, σ : 5.35. d Panel-4, mean: 30.44, σ : 7.97. e Panel-5, mean :30.50, σ :5.82 (Total subpixel: 2,940, Assembly accuracy: 99.93%).



Supplementary Fig. 10 | Schematics of fabrication of EL device based on the fin-LEDs

a Fabrication of electrode. **b** Fin-LEDs DEP assembly. **c** SU-8 planarization coat & SiO₂ anchor deposition. **d** TCO deposition. **e** SEM image of fin-LEDs EL Device. Scale bar represents 1 μ m

Assembly	Transfer method	Chip size (µm ²)	Chip cost	Transfer Cost	Transfer speed	Transfer yield (%)	Ref
Pick up	Elastomer stamp	~1,256.00	Middle	High	1M hr-1	99.50	[1,2]
	Laser	~1.00	Low~Middle	Middle~High	100M hr-1	99.80	[1,2]
Fluidic assembly	Wave energy	~1,256.00	Middle	Middle	NR	97.00	[3]
	Gravity and capillary force	~1,256.00	Middle	Middle	1 M hr ⁻¹	99.90	[4]
	Vander walls force	1,256.00	Middle	Middle	54K hr-1	99.99	[5]
	Molten solder	706.50	Middle	Middle	1M hr ⁻¹	99.88	[6]
	magnetic-force-assisted dielectrophoretic self- assembly technology	~980.20	Middle	Middle	NR	99.50	[7]
		~0.19	Low	Low	NR	99.98	[8~13]
	Dielectricphoresis	2.80	Low	Low	1M hr ⁻¹	99.93	Our works

Supplementary Table 1 | Comparison for micro-LED mass transfer method

Volume (µm ²) Shape	Area of MQW	Orientation selective ratio	Aligned direction	Wavelength (nm)	Brightness (cd m ⁻²)	EQE (%)	Ref
	(μm^2)	(%)					
0.49, rod	0.20	NR	Horizontal	515	2,130	NR	[8]
					(20V)		
0.66, rod	0.23	74.4	Horizontal	515	NR	NR	[9]
0.97, rod	0.22	NR	Horizontal	448	NR	8.9~20.2	[10]
1.32, rod	0.26	NR	Horizontal	445	NR	9	[11]
1.32, rod	0.26	NR	Horizontal	460-464	NR	19.6~22.2	[11]
2.36, rod	0.50	NR	Horizontal	440	NR	2.6	[12]
7.64, rod	1.79	NR	Horizontal	445	NR	NR	[13]
0.86, dot	0.79	NR	Vertical	448	1,070.40	6.21	[14]
					(10 V)		
2.17, fin	2.28	91.3	Vertical	448	8,640	9.1	Our
					(5 V)		works

*NR Non-reported

Supplementary Table 2 | Comparison for micro-LED electric properties in sizes below 10 μm^2

	Dielectric constant (ε ₀)	Electrical conductivity (S m ⁻¹)	Reference
n-GaN	8.9	$20 imes 10^3$	[7]
p-GaN	8.9	2.38×10^{-3}	[15]
ΙΤΟ	3.2	10^{6}	[15]
SiO ₂	3.9	1×10^{-12}	[16]
cetone	20.7	$20 imes 10^{-6}$	[17]

Supplementary Table 3 | Physical properties of materials used in FEM simulation

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