Supporting Information

Bi-facial Color-Tunable Electroluminescent Devices.

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Supporting Figures

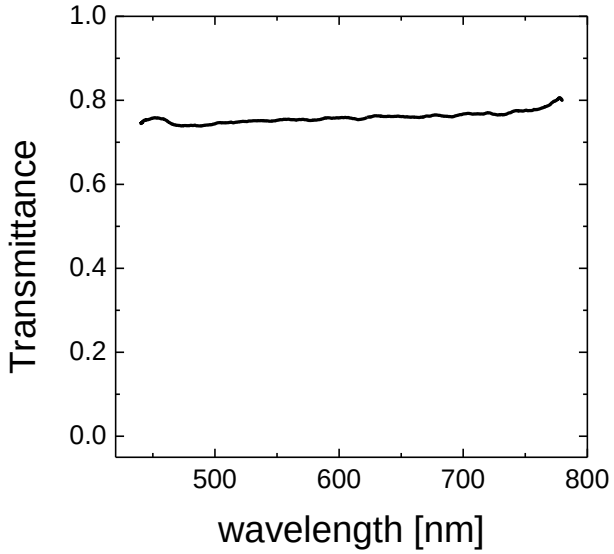

Figure S1 Transmittance spectrum of the AgNW electrode

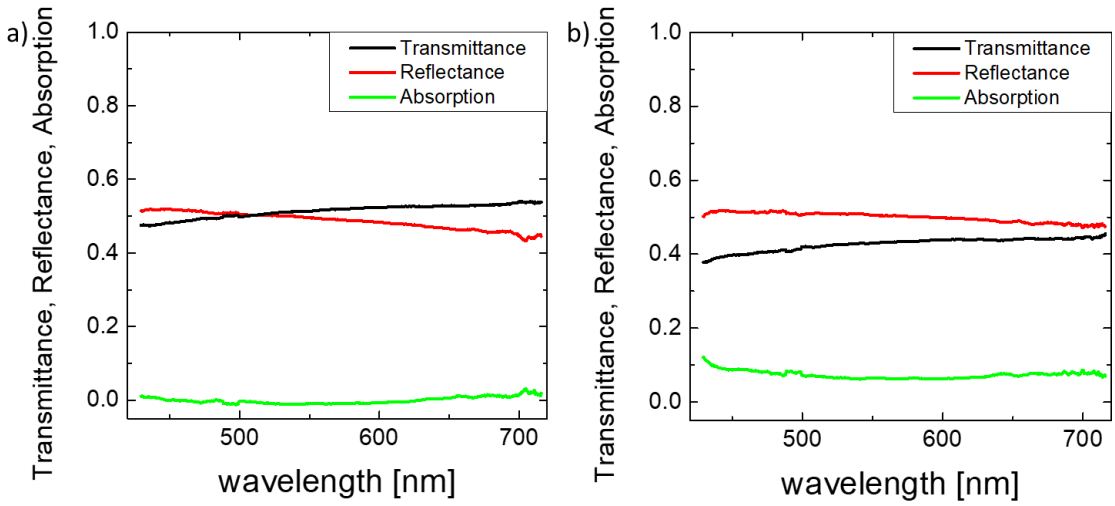

Figure S2 a) Transmittance, reflectance and absorbance spectra of the dielectric interlayer measured against air(average reflectance 48.7%, average transmittance 51.3%) b) Transmittance, reflectance and absorbance spectra of the dielectric layer and the EL-layer combined against air (average reflectance 50%, average transmittance 42.6%). Note that reflectance and transmittance are 100% diffuse. No specular reflectance and transmittance can be measured.

Figure S3 Photograph of the bi-facial ACEL device placed on a computer screen, which displays the logo of the University of Wuppertal. The device is clearly translucent with a high degree of haze.

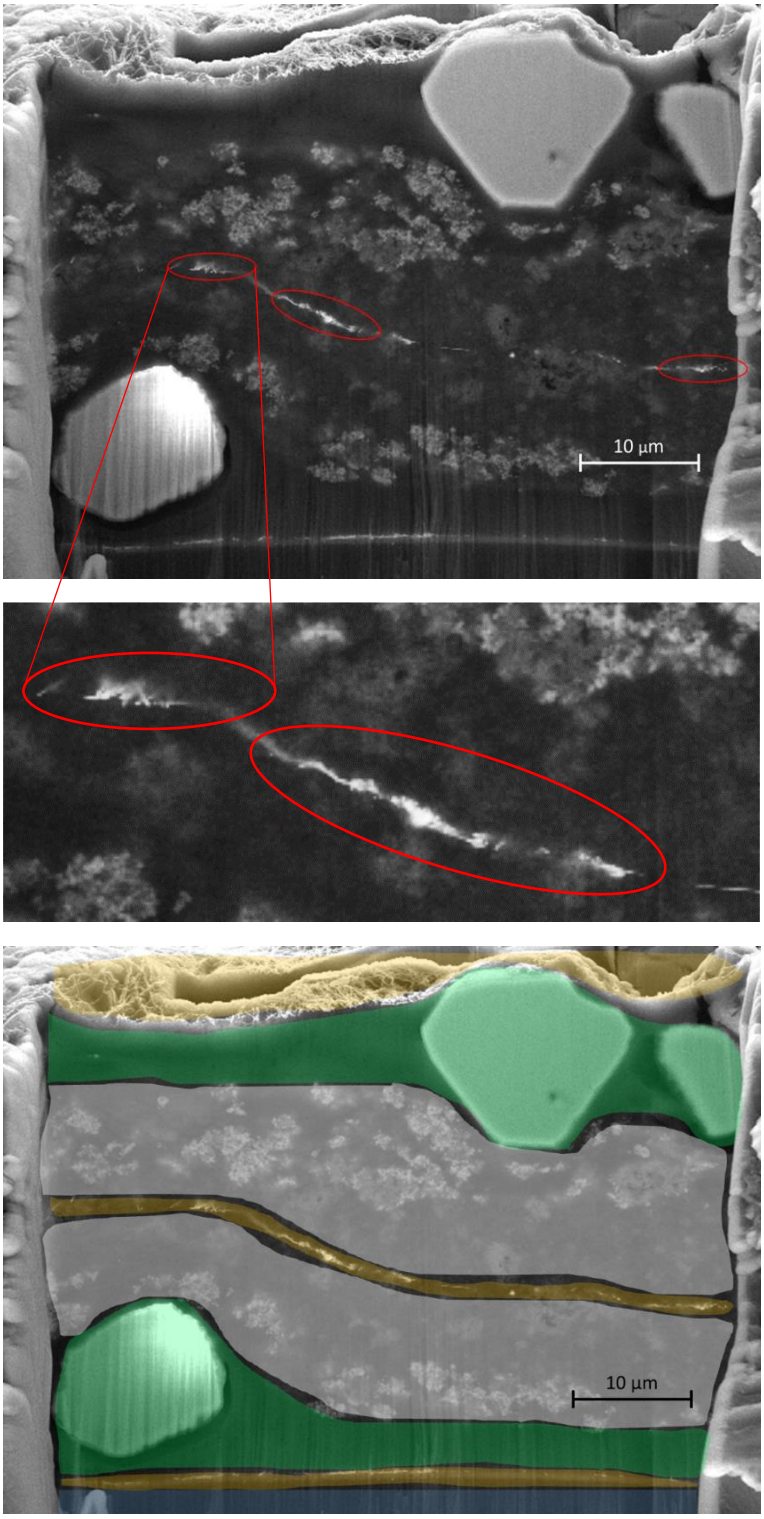

Figure S4 Scanning electron microscopy image (15 kV acceleration voltage, secondary electron detector) of a focussed ion beam cut cross section of the tandem ACEL device as shown in figure 2a). The different layers are highlighted as following: PET substrate in blue, nanowire electrodes in yellow, (note, some clearly visible Ag-NWs in the center-electrode are highlighted with red ellipses) EL-Layer in green, isolation layer in white/grey. Note that the white particles are the actual luminescent particles. As clearly visible the emitting layer consists of large EL-particles.

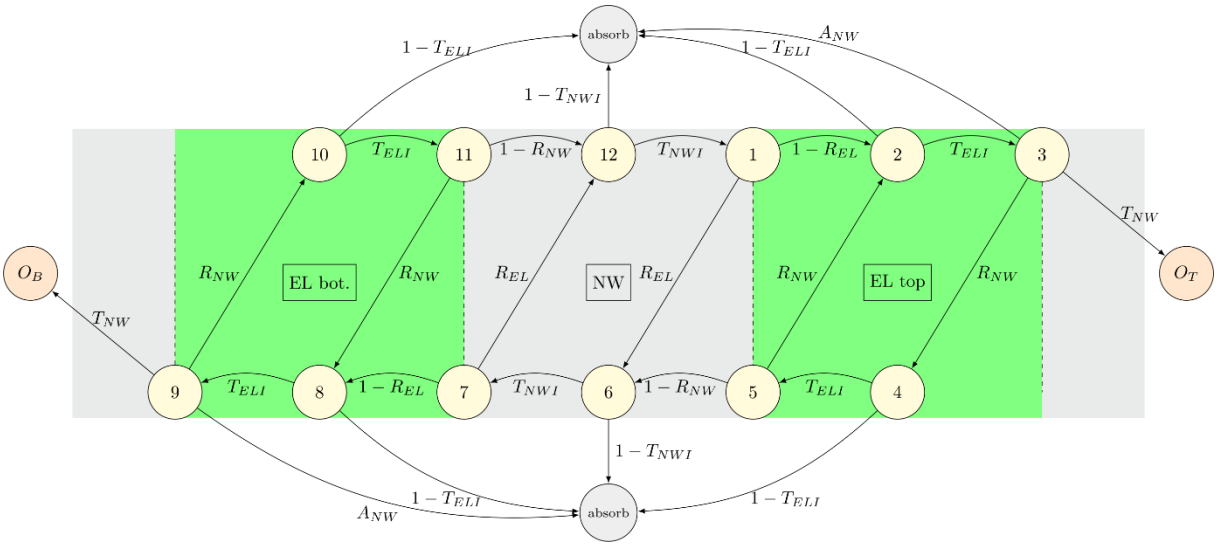

Figure S5 Transfer matrix model to calculate the loss of luminance in the non-operated EL sub device. We simplified the device structure and combined the dielectric and the luminescent layer in one layer (denoted EL). We introduced various nodes (displayed as yellow circles, numbered 1-12). The nodes positioned at an interface represent the reflection at the interface, while the nodes in the center of a layer represent the absorption in the layer. The nodes (1-3; 10-12) in the upper half of the scheme represent the direction of light propagating from the left to the right. The other nodes (4 – 9) display the direction of light from the right to the left. The node labelled with 1 represents the light emitted from the bottom sub device that has passed the center AgNW electrode and now hits the AgNW EL interface of the top sub-device, were the light is either reflected (with a probability of R_{EL}) or is able to propagate into the EL-layer with a probability of $1\text{-}R_{EL}$. From there on the photons gets either transmitted (T_{ELI}) or absorbed ($1\text{-}\ T_{ELI}$), and so on… The orange circles O_T and O_B on the right and left side represents the light coupled out to the top and the bottom electrode of the device. The grey circles, labelled "absorb", represent all the absorbed portion of light in the device.

$$
M = \left(\begin{array}{cccccccccccc|ccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{NWI} & 0 & 0 & 0 \\
1-R_{EL} & 0 & 0 & 0 & R_{NW} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & T_{ELI} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & R_{NW} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & T_{ELI} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_{EL} & 0 & 0 & 0 & 1-R_{NW} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & T_{NWI} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1-R_{EL} & 0 & 0 & 0 & R_{NW} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{ELI} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & R_{NW} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{ELI} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & R_{EL} & 0 & 0 & 0 & 1-R_{NW} & 0 & 0 & 0 & 0 \\
\hline
0 & 1-T_{ELI} & A_{NW} & 1-T_{ELI} & 0 & 1-T_{NWI} & 0 & 1-T_{ELI} & A_{NW} & 1-T_{ELI} & 0 & 1-T_{NWI} & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & T_{NW} & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & T_{NW} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}\right)
$$

Figure S6 Resulting transfer matrix for the schematics in Figure S4. We calculated "internal" transmission factors T_{ELI} and T_{NWI} by using the measured transmission, factoring out the reflectance since the reflection and transmission in this model is split in different steps. The following equations show the calculation of the "internal transmission factors".

We used $T_{EL} = 0.43,\ T_{NW} = 0.75\ , and\ \ R_{NW} = 0.25.$ T_{ELI} and T_{NWI} have been calculated as follows:

$$T_{ELI} = \frac{T_{EL}}{(1-R_{EL})} = \frac{0.43}{(1-R_{EL})} \qquad \text{(S1)}$$

$$T_{NWI} = \frac{T_{NW}}{(1-R_{NW})} = \frac{0.75}{(1-0.20)} = 0.9375 \qquad \text{(S2)}$$

Each column represents a node and the propagation to the node represented by the row. For example the transfer from node 1 is represented by column 1. In the scheme figure S4 we can see that with a probability of R_{EL} light is reflected to node 6 (compare the matrix point column 1 row 6) or propagates with a probability of $1\text{-}R_{EL}$ to node 2 (Column 1 row 2). The rest follows accordingly. The matrix highlighted in red is the resulting matrix for the propagation and reflections between the nodes 1-12 in the scheme shown in Figure S4. The columns 13, 14, 15 highlighted in orange show the transfer from the internal reflections and transmissions to the final nodes (absorption, or emission to either side). Row 13 expresses the transfer of the nodes 1 – 12 to the absorption node, row 14 to the left side (representing the bottom side of the device) and row 15 to the right side (top side of the device).

The identity matrix highlighted in green express the 3 final states for a photon. Row/column 13 represents the "absorb" node, Row/column 14 represents the emission from the bottom side of the device, row/column 15 the emission trough the top device. Taking the n-th power of the matrix M, i.e. M^n (where n is the number of steps the photon took inside of the device), with $n \rightarrow \infty$ results in a matrix where the first column shows the probability of a photon being at a certain position in the device after n steps in the device. The values at the rows 13, 14 and 15 represent the absorption, emission to the bottom side and emission to the top side. Note, the calculation converges for $n = 20$. We calculated the M^{20} matrix, using all known variables with R_{EL} as only unknown. From the comparison of the luminance from top side of the single bi-facial EL device and the luminance of the bottom device measured through the top electrode of the tandem device, we determine a ratio of about 46%. Therefore the value in column 1 row 15 of the M^{20} matrix ($M^{20}(15,1)$) has to be 0.46 (46%). We solved the equation $M^{20}(15,1)=0.46$ for R_{EL} with GNU Octave. The calculation results in 1 solution in the amount of solutions [0;1] for $R_{EL}=0.52$ (52%). In addition to the already known overall emission to the top side of 46%, we are now able to calculate the theoretical emission to the bot side of 24% and the absorption in the device of 30%.

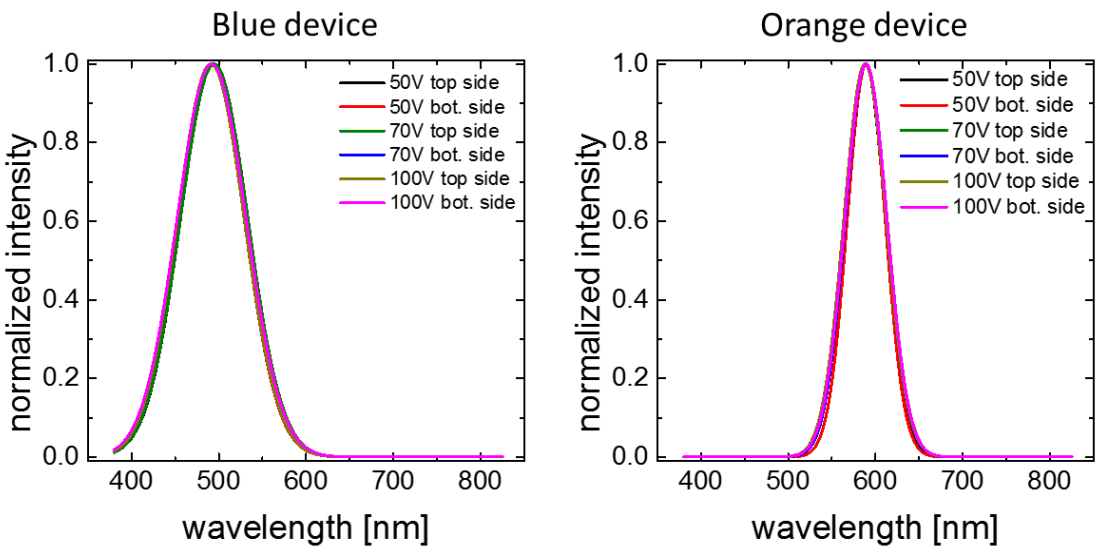

Figure S7 Normalized and smoothed emission spectra for the blue and orange sub device at all shown voltages from both sides.

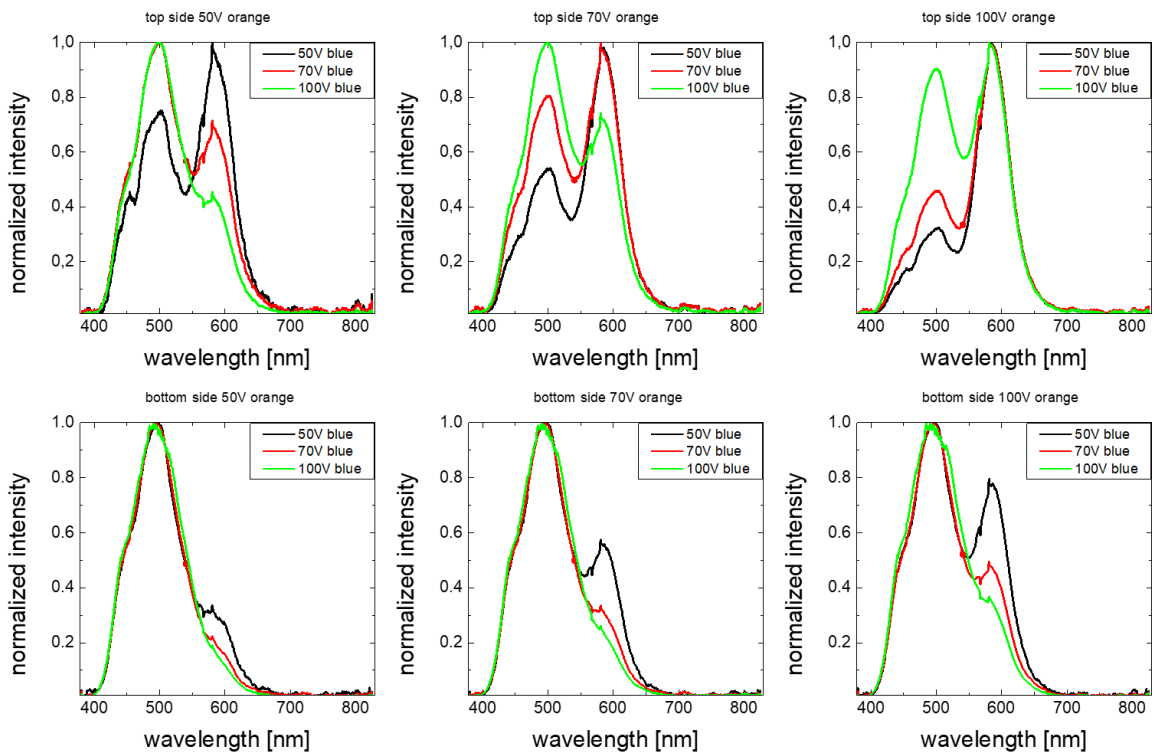

Figure S8 Emission spectra for all shown configurations measured from both sides.

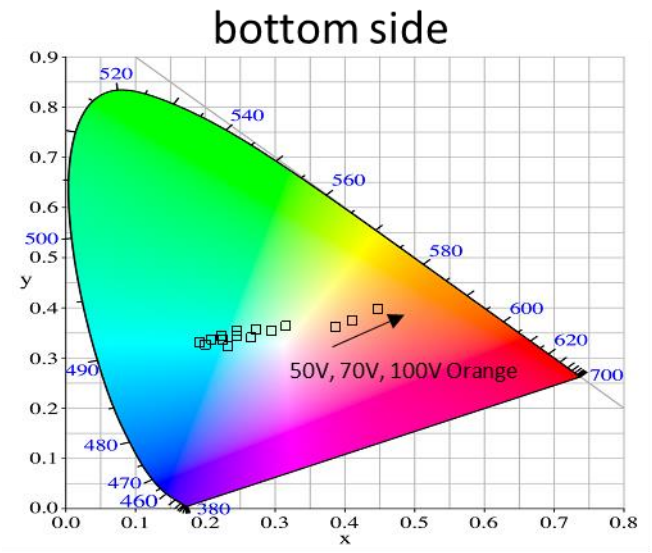

Figure S9 CIE diagram for all measured spectra from the bottom side

Supporting Tables

Table S1. CIE Coordinates for all shown configurations in Figure S7

Voltage orange [V]	Voltage blue [V]	*x*	*y*
50	0	0.39	0.36
70	0	0.42	0.39
100	0	0.45	0.41
0	50	0.25	0.35
50	50	0.29	0.36
70	50	0.34	0.38
100	50	0.37	0.39
0	70	0.23	0.35
50	70	0.27	0.36
70	70	0.30	0.37
100	70	0.34	0.39
0	100	0.21	0.35
50	100	0.24	0.37
70	100	0.26	0.37
100	100	0.29	0.38