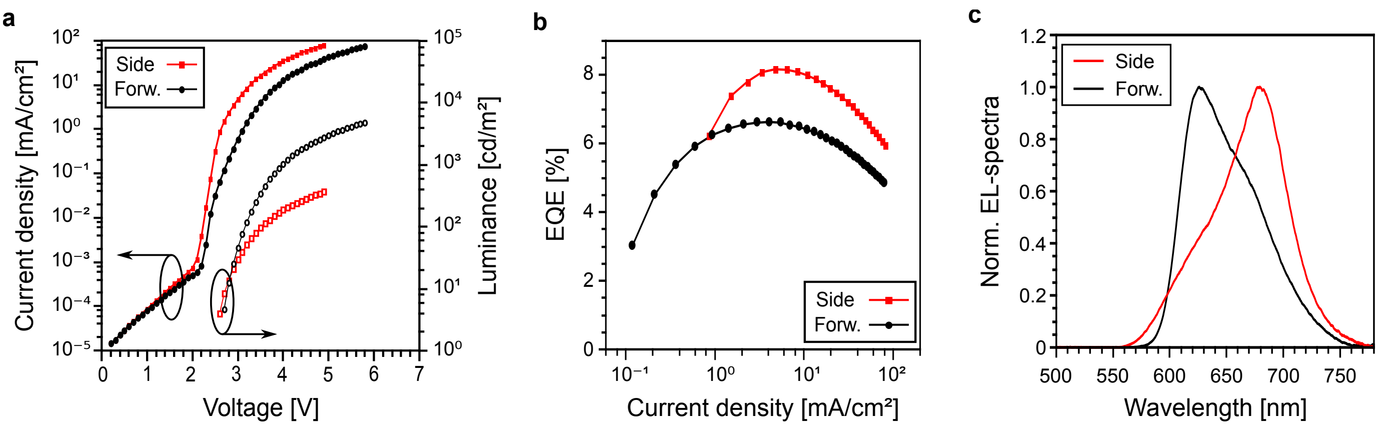

Figure 2 | **Electro optical device characteristics.** a) The current density as a function of the driving voltage is shown in black, the respective forward luminance in red. b) The resulting EQE for both units. c) EL-spectra for both the side and the forward emission unit, at their emission maximum. The peaks show a spectral distance of 54 nm.

here, because the photoluminescence quantum yield of the emitter used ($Ir(piq)_3$) is only approximately 50%.[18,19] Fig. 2c shows the electroluminescence (EL) spectra of OLED 1 and OLED 2 for their respective maximum intensity emission, which are spaced by 54 nm.

Optical design of the beam-shaping OLEDs

The final OLED stack for effective beam-shaping should show very anisotropic emission patterns for the two units employed. Therefore, one needs to analyse the explicit expression of the spectral radiant intensity (SRI) per unit area $I(\lambda, \theta)$, as given by Furno *et al.*:[10]

$$I(\lambda,\theta) = \frac{hc}{\lambda} \cdot \frac{I}{e} \cdot \gamma \cdot s_{\mathrm{EL}}(\lambda) \cdot \underbrace{\eta^{\star}_{\mathrm{rad}}(\lambda) \cdot \frac{P_{\mathrm{out}}(\lambda,\theta)}{F(\lambda)}}_{\text{Cavity-Mode}}, \tag{1}$$

with the wavelength λ, the viewing or emission angle θ, Planck's constant h, the speed of light in vacuum c, the current I, the elementary charge e, the charge carrier balance factor γ, and the EL spectrum of the embedded emitter $s_{\mathrm{EL}}(\lambda)$, which normally gets identified with the directly-measurable photoluminescence (PL) spectrum $s_{\mathrm{PL}}(\lambda)$.[20] The second-to-last factor $\eta^{\star}_{\mathrm{rad}}(\lambda)$ is the effective radiative efficiency of the emitter, which is the ratio of the radiative and the total decay rate in the presence of a microcavity.[10,20,21] The outcoupled power spectrum per unit solid angle $P_{\mathrm{out}}(\lambda,\theta)$ is the only factor that contains an explicit angular dependency and is divided by the Purcell-Factor $F(\lambda)$.[22] Thus, the factor $\frac{P_{\mathrm{out}}(\lambda,\theta)}{F(\lambda)}$ gives the emission affinity for a photon of a given wavelength λ under an angle θ within the microcavity. Accordingly, for a given emitter $s_{\mathrm{PL}}(\lambda)$, only the last two factors in equation (1) define the final out-coupled spectra of the electroluminescent device. From an engineering point of view, it is the total thickness of the cavity, the reflectivity of the mirrors and the positioning of the emitting layers that define these two factors. Hence, they are referred to as cavity mode. Influences of the microcavity on the final out-coupled spectrum of OLEDs have been widely analysed before and even preferential side emission has been observed previously.[10,21–23] However, none of these studies have investigated a possible sideward emission with respect to maximum efficiency.