technical note

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Lifetime cathodoluminescence mapping

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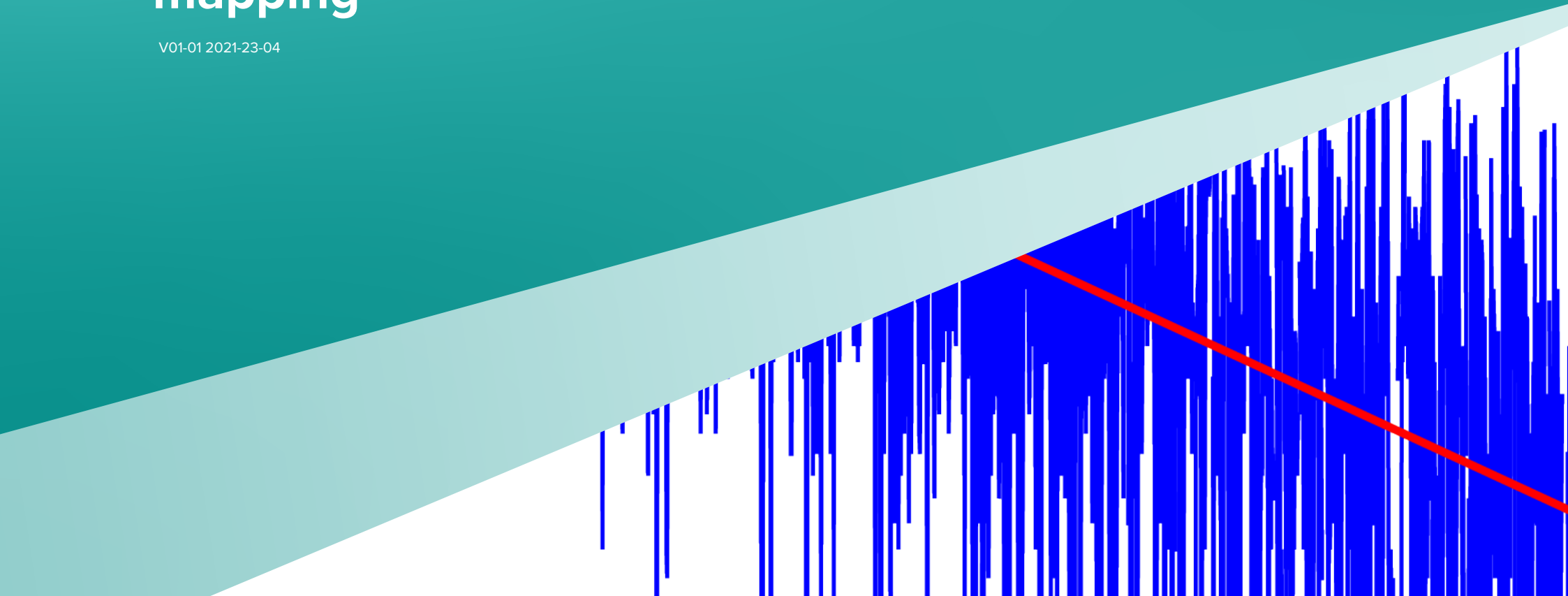

Lifetime cathodoluminescence mapping

Light emission from a material is a complex dynamic process in which many different mechanisms can play an important role. Depending on the exact materials and processes involved, the dynamics can cover a large range of time-scales from the order of seconds all the way into the attosecond (10^{-18} s) regime. By studying these dynamics one can therefore obtain detailed insight into a large variety of physical processes and material properties.

Spontaneous light emission process in time

When a material is excited by electrons (or light as in photoluminescence), valence electrons in the material are brought into an excited state. The excited system can then decay into the ground state with the emission of a photon in a spontaneous emission process as shown in **Figure 1 (a)**. The decay process is stochastic in nature and for a perfect two level system is described by a single exponential as is shown in the decay trace in **Figure 1 (b)**. Measuring when light is emitted after the excitation of the material allows to retrieve this exponential form, where the lifetime τe is the point in which the exponential reaches 1/e (or ~0.368) of the initial value. The average decay rate Γ_{tot} is the inverse of τ_e.

As described by Fermi's golden rule, the magnitude of Γ_{rad} depends on intrinsic material/emitter properties but also on the local density of optical states (LDOS) which describes the number of optical states the emitter can decay into at a given position in space. This LDOS can be altered if emitters are placed in a different dielectric environment. Substrates or mirrors, nanoantenna systems, metamaterials/surfaces, photonic crystals, or (nano)cavities can all be used to enhance (or, in some cases, suppress) the LDOS [1]. These enhancements can be energy (wavelength) and momentum result the light emission process can be tailored for specific applications.

In real materials not all of the excitations are converted into light and some of the energy is lost to e.g. phonons. As such the total decay-rate is built up out of radiative (light emission) and non-radiative (no light emission) decay $\Gamma_{tot} = \Gamma_{rad} + \Gamma_{nrad}$. Furthermore, the two level approximation is often invalid and multiple (interacting) transitions over

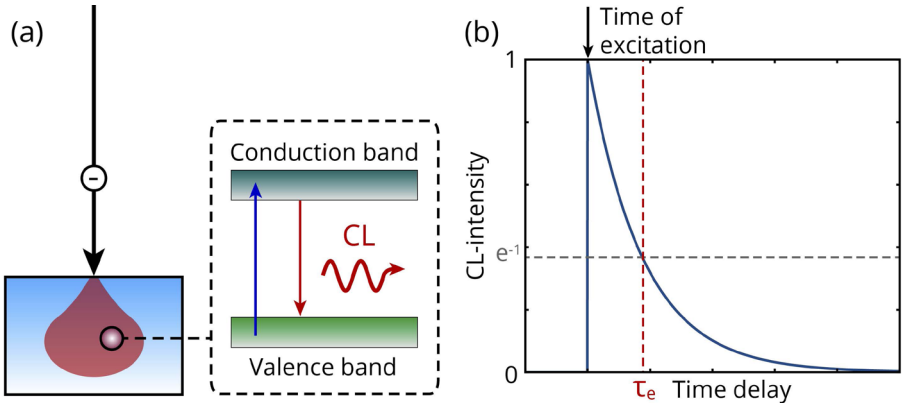

Figure 1 (a) Schematic of the CL emission process for a semiconductor system. (b) An example of a single-exponential decay where the time of excitation and the characteristic decay time τ_e are indicated. The rise time here is chosen infinitesimally small leading to a vertical ramp-up of the signal at the time of excitation.