technical note | sparc spectral

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Cathodoluminescence $g^{(2)}$ imaging

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Cathodoluminescence (CL) emission has many interesting properties that can be used to characterize (nano)materials. CL emission from a material is a dynamic process and a wealth of information can be extracted by investigating its behavior in the time domain. The $g^{(2)}$ function, well-known from quantum optics, provides a very useful tool in this context as we will show in this technical note.

Second order autocorrelation function: $g^{(2)}(\tau)$

In a beam of light, photons are distributed in time in a particular manner. This distribution can be described by the normalized second order autocorrelation function $g^{(2)}(\tau)$ which represents the probability to observe two photons spaced in time by a delay τ.

$$g^{(2)}(\tau)=\frac{\langle I(\tau)I(t+\tau)\rangle}{\langle I(t)\rangle^2}$$

$g^{(2)}(0)$ is used to denote the amplitude of the $g^{(2)}$ function at zero delay. The shape of the $g^{(2)}$ function depends strongly on the type of light source. For a fully coherent Poissonian source with a single frequency such as a laser $g^{(2)}(\tau) = 1$. For light with a reduced coherence (also referred to as chaotic light) originating from a discharge lamp for example, $g^{(2)}(0) = 2$. This effect is referred to as bunching because photons are grouped together in time. The bunching process for chaotic light will typically only be visible at fs timescales and is difficult to observe in most experiments because of limitations in the time resolution. As we will show below, bunching can be seen in CL experiments on longer timescales for different reasons.

Alternatively, a single-photon emitter such as a single quantum dot, also has a characteristic $g^{(2)}$. As the name implies a single-photon emitter can only emit one photon at a time and therefore it is impossible to observe coincident photons.

As a result the $g^{(2)}$ function drops below 1 with $g^{(2)}(0) = 0$, which is referred to as antibunching. This signature can be used to identify and characterize such quantum sources of light. For more elaborate theoretical background on the $g^{(2)}$ function and (anti)bunching we refer the reader to Refs. 1 and 2. The different characteristic $g^{(2)}(\tau)$ curves described above are schematically shown in **Figure 1**.

(Anti)Bunching in Cathodoluminescence

As mentioned, in the case of a single-photon emitter the $g^{(2)}$ will show antibunching. This effect is also present if such a source is excited with electrons as first demonstrated by Tizei *et al.* on NV^0-center emission in diamond [3]. Owing to the high spatial resolution, CL can be used to precisely localize, identify, and characterize single-emitters [3,4].

Alternatively, many extended solid state systems can be regarded as an ensemble of light emitters (a bulk semiconductor or a series of quantum wells for example) and here it is possible to observe pronounced bunching [5 - 9] in the CL emission, an effect which is