# Spontaneous emission from active dielectric microstructures

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**09.15 QFC4**

# Variable coherence in determining the scattering parameters of diffuse media using laser speckle

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We demonstrate the application of a variable-coherence laser source for determining the scattering parameters of a diffuse medium and the potential for imaging spatially-dependent scatter. A key concept in this work is the ability to synthesize a variable-coherence source by frequency modulating a tunable laser diode (with a center wavelength of 850 nm) at a rate much faster than the integration time of the detector. This allows for a rapid measurement and the adaption of laser coherence to the degree of scatter, which we show is critical in obtaining the necessary sensitivity

The speckle intensity statistics are described by the contrast ratio, which we have previously shown can be used to extract material parameters using light of fixed coherence by varying the material thickness [1]. The experiments used commercially available white acrylics (with the scattering due to ~50 nm $TiO_2$ particles suspended in the acrylic background) as the diffuse medium in a transmission geometry. The speckle contrast ratio dependence upon the source linewidth was measured, with the results shown in Fig. 1. The theoretical fits were obtained using an approximate Green's function for the diffusion equation.

To demonstrate sensitivity of the speckle contrast ratio to scattering variations, we have performed a number of experiments to collect imaging-type data [2]. This data shows a spatially-varying contrast ratio which can be used to reconstruct photon transit time distributions. In the images of Fig. 2, the difference of contrast ratio between the inhomogeneous and homogeneous cases is shown Lighter shades represent a higher contrast than in the homogeneous case, and darker shades represent a lower contrast ratio. In Fig 2(b) one can see a region of higher contrast ratio corresponding to the localized reduction of scattering introduced by a void Conversely, in Fig. 2(d), one can see a region of lower contrast ratio due to the localized increase in scattering caused by a white acrylic inhomogeneity. No localization of the inhomogeneities is observed for the 5 MHz linewidth used in Figs. 2(a) and 2(c), demonstrating the importance of the source coherence.

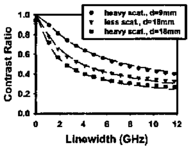

Fig 1. Contrast ratio data as a function of laser linewidth for two different acrylics The symbols are experimental data, and the dashed lines are theoretical fits The top and bottom curves are for the heavily scattering acrylic with $\mu_s' = 12.5\,\mathrm{cm}^{-1}$ The middle curve is for the less scattering acrylic with $\mu_s' = 6\,\mathrm{cm}^{-1}$. The slab thickness is $d$.

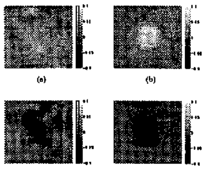

Fig. 2 Contrast ratio difference images for each inhomogeneity at two laser linewidths: (a) void at 5 MHz; (b) void at 17 GHz; (c) heavy scatterer at 5 MHz; (d) heavy scatterer at 17 GHz The variation in contrast ratio is shown by the intensity-bars to the side of each image.

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**09.30 QFC5**

# Spontaneous emission from active dielectric microstructures.

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Spontaneous emission is one of the key factors that determine the noise properties of photonic devices and the pump power threshold of lasers. The spontaneous emission in dielectric microstructures (micro-cavities, photonic crystals, optical waveguides, etc.) can to some extend be controlled and engineered due to the dependence of the emission rate on the location and polarisation of the emitters in the structure [1,2]. This paper addresses the methods of quantum electrodynamics of dielectric media which enable calculation of the local rate of spontaneous emission in active microstructures.

For passive structures the spontaneous emission may be derived by expanding the radiation field in power-orthogonal modes normalized to one quantum of energy, and using the Fermi Golden Rule. This approach was used in [1] for calculating the position dependence of spontaneous emission in passive photonic crystals. However, for active materials the mode concept is problematic, and it is more convenient to express observable quantities in terms of the field operators and generating currents. The total rate of spontaneous emission is given by

$$\Gamma = \frac{2\mu_0}{\hbar}\mathrm{Im}\left(\int\langle \vec{j}^{+}(\vec{r}')\cdot\bar{G}(\vec{r}',\vec{r}'')\cdot\vec{j}(\vec{r}'')\rangle\, d^3\vec{r}'d^3\vec{r}''\right) \tag{1}$$

where $\vec{j}(\vec{r})$ is the generating current, and $\bar{G}(\vec{r}',\vec{r}'')$ is the classical transverse Green's tensor that determines the electric field in terms of the transverse current. For materials with gain the tensor can be derived from the solutions to the homogeneous wave equation and the adjoint wave equation.

As an example we show in Figure 1, in polar coordinates, the distribution of spontaneous emission going into radiation modes from an active optical fiber. The distributions are shown for the emitter in the center of the fiber core and at the edge of the fiber core, respectively. The optical fiber has the core refractive index 1.45, cladding refractive index 1.43, core radius 2 µm. The emission wavelength is 1508 nm. The emission rate $\Gamma_z$ is for dipoles with orientation along the fiber axis, $\Gamma_\perp$ is the sum of emission rates for dipoles with orientation perpendicular to the fiber axis, and $\Gamma_{tot}$ is the sum of these two emission rates.

The presentation will include an analysis of the effects of gain on the radiation pattern and the ratio of radiation into the guided mode(s) for active optical fibers.

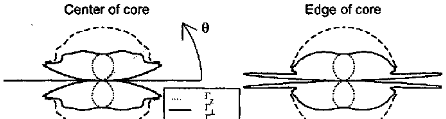

Figure 1: Off-axis angular distribution of spontaneous emission from an active optical fiber

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