Distributed Anti-Stokes Raman Thermometry

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Introduction

Distributed Temperature Sensing (DTS) is a critical need for several applications including down-hole monitoring of oil and gas exploration, power cable and transmission line monitoring, leak detection in oil and gas pipelines and fire detection in tunnels. For such applications, optical fiber is an attractive choice because of its thread-like structure which can be laid across pipelines, tunnels and measure temperature for several tens of kilometers due to its low attenuation constant.

Raman scattering in optical fibers is well suited for the DTS application. Raman scattering is an inelastic scattering process, where energy exchange takes place between the molecular system and the incident photons. In this process, vibrational energy of the molecules either feed off (Stokes scattering) or feed in to (anti-Stokes component) the photon energy, resulting in the generation of new frequency components (Fig. 1). A key attribute of the Raman scattering process is that the anti-Stokes scattering is

$$R(T) = \left(\frac{\lambda_s}{\lambda_{as}}\right)^4 \exp\left(\frac{-\Delta E}{K_B T}\right)$$

strongly dependent on temperature, whereas the Stokes scattering is not. Hence, by taking the ratio *R(T)* of the two components one can estimate the absolute value of temperature '*T*' experienced by the fiber. λ_s and λ_{as} are the Stokes and anti-Stokes wavelength, ΔE is the peak vibrational energy, and K_B is the Boltzmann constant.

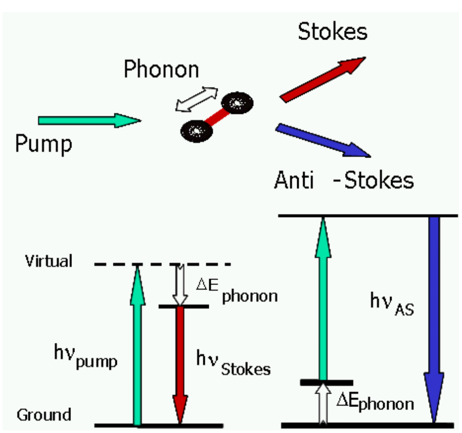

Figure 5: Illustration of Raman scattering mechanisms and the corresponding energy levels.

Distributed Anti-Stokes Raman Thermometry

The approach that we have followed for distributed temperature sensing is to use Raman scattering principle in tandem with optical time domain reflectometry (OTDR), a technique commonly referred to as Distributed Anti-Stokes Raman Thermometry (DART). A short duration of light pulse is launched into the sensing fiber and the time of flight between this pulse and the backscattered signals that reach the receiver can be used to estimate the precise location from where backscattering has occurred. The experimental setup used for Distributed anti-Stokes Raman Thermometry (DART) is illustrated in Fig. 2.

Figure. 2 Experimental setup of DTS

To understand the trade-off between cost and performance, we developed a model that computes the backscattered Stokes, anti-Stokes and Rayleigh spectrum components as a function of distance for a given temperature map. The transmitter, fiber, optical filter, and receiver parameters can be fed to the model and their effect on the system performance may be evaluated. In addition, the model also allows for the use of signal processing techniques such as averaging and filtering for further improving SNR. Using the model, we designed a system with a semiconductor pulsed laser, circulator and InGaAs avalanche photodiode.

In Fig. 3, we show experimental and estimated (using model) distributed temperature maps, where three sections of fiber are maintained at different temperatures using two ovens and a refrigerator. An optical pulse of 85 mW and width of 80 ns was launched while the APD used a reverse bias voltage of 48 V. The laser pulses were fired at a repetition rate of 1 KHz and the backscattered trace corresponding to each pulse is averaged for 220K times to achieve a signal to noise improvement of 25 dB. The DART system has been demonstrated with 3 ºC accuracy.

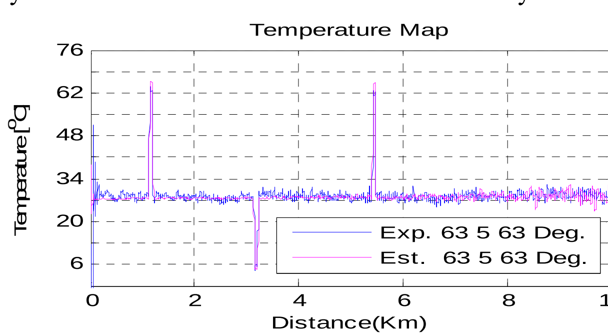

Fig. 3 Experimental and estimated temperature map

Experimental Optics
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