Hollow Core Photonic Crystal Fibers in High-Precision Sensing Applications

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Hollow Core Photonic Crystal Fibers (HC-PCFs) are a novel type of optical fibers, featuring several physical characteristic making them suitable for the development of high precision, next generation optical and optomechanical sensors. The hollow core and single-material structure allow for high power delivery and strongly increase the stability of interferometric fiber optic gyroscopes (IFOGs) and resonant fiber optic gyroscopes (RFOGs) by reducing non-reciprocal noise due to temperature fluctuations and electromagnetic radiation [1, 2, 3, 4, 5]. We report on the characterization of optical guiding properties of HC-PCFs as well as their application as high-resolution temperature sensors through optical trapping and guidance of dielectric probes in the hollow core.

Interferometric and Resonant fiber optic gyroscopes (IFOG & RFOG)

HC-PCFs can improve accuracy of IFOGs [1, 2, 3] (Fig. 1) and RFOGs [4, 5] (Fig. 2) by offering reduced non-reciprocal noise compared to traditional fibers: light propagation in the hollow core improves stability to temperature (Shupe effect) and radiation (Kerr effect). Different HC-PCFs types may be best suited for IFOGs or RFOGs depending on favorable parameters, such as low bending loss or large mode area.

fig. 1

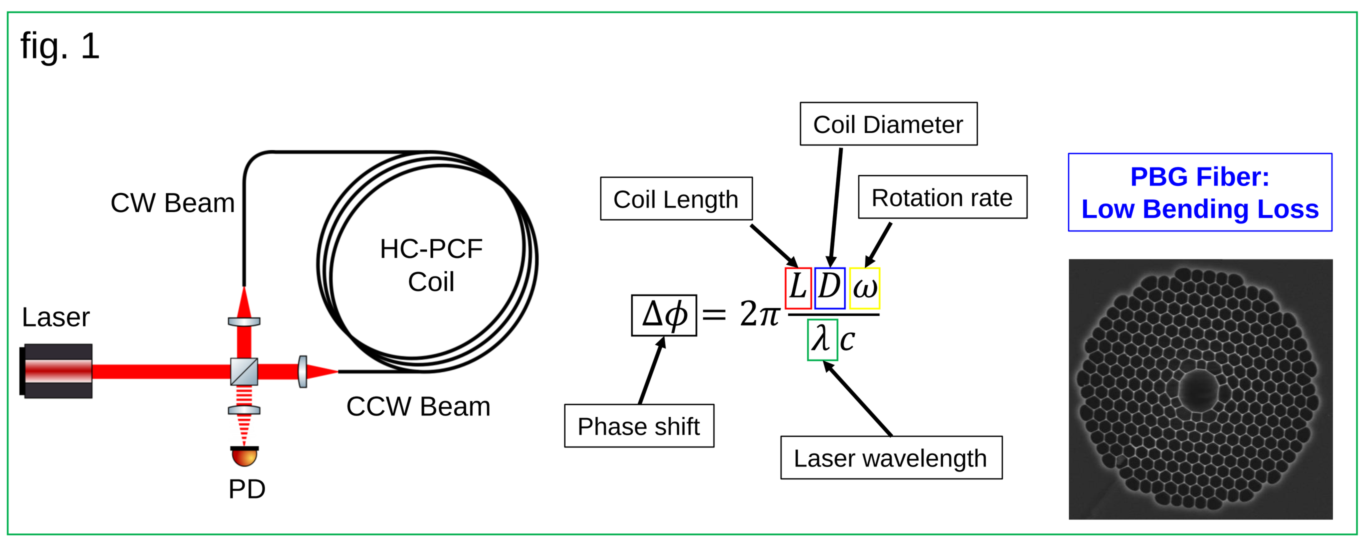
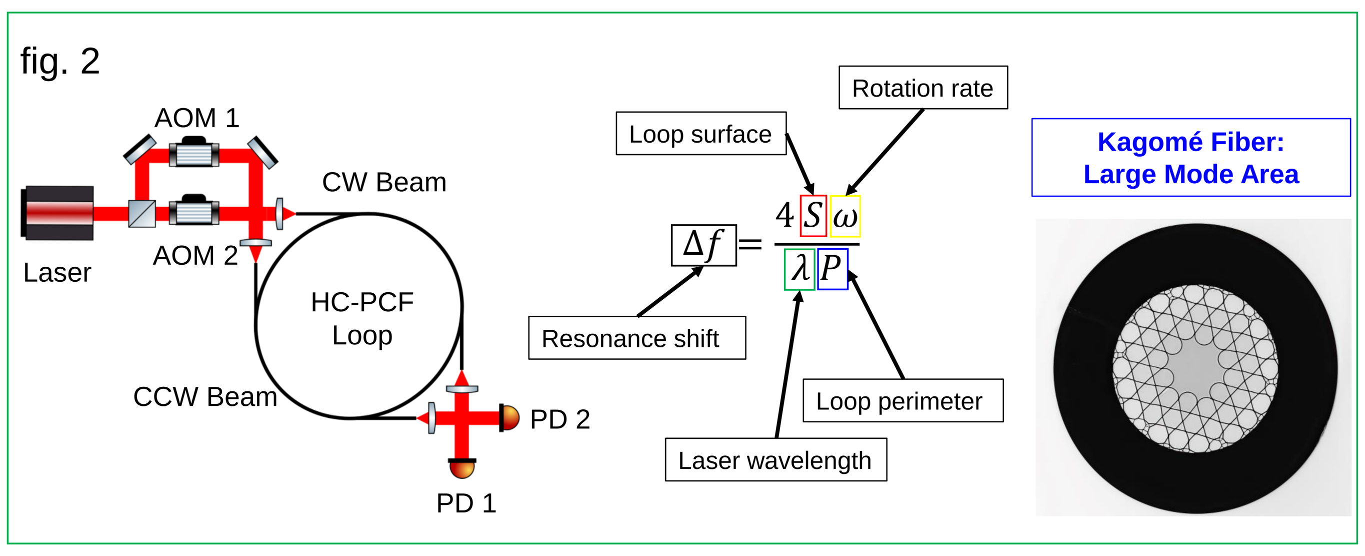


fig. 2



Optical modes and forces in HC-PCFs

Optical modes propagating in HC-PCFs (fig. 3) can be computed through numerical simulations (fig. 4): the resulting modes resemble cylindrical vector modes propagating in traditional fibers. Such modes can be used to compute optical forces on optically trapped particles through a Generalized Lorenz-Mie Theory (GLMT) [6]. Expansion of cylindrical EM fields through a GLMT can be determined analytically [7], allowing for accurate prediction of size dependent features of optical forces, such as Mie resonances (fig. 5).

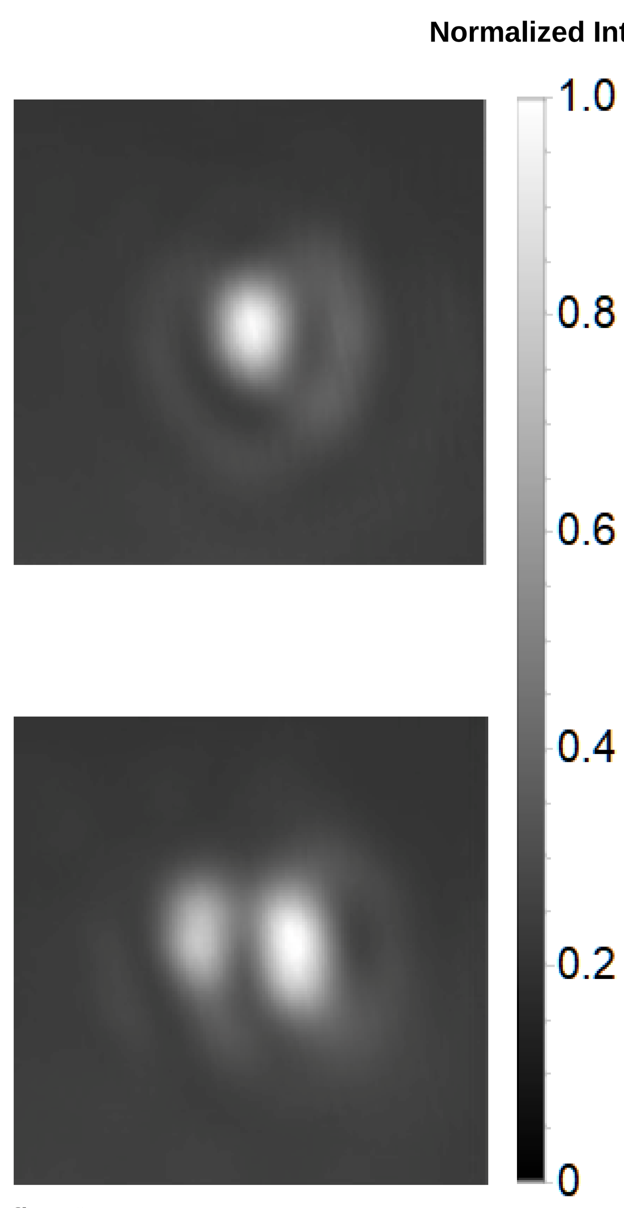


fig. 3

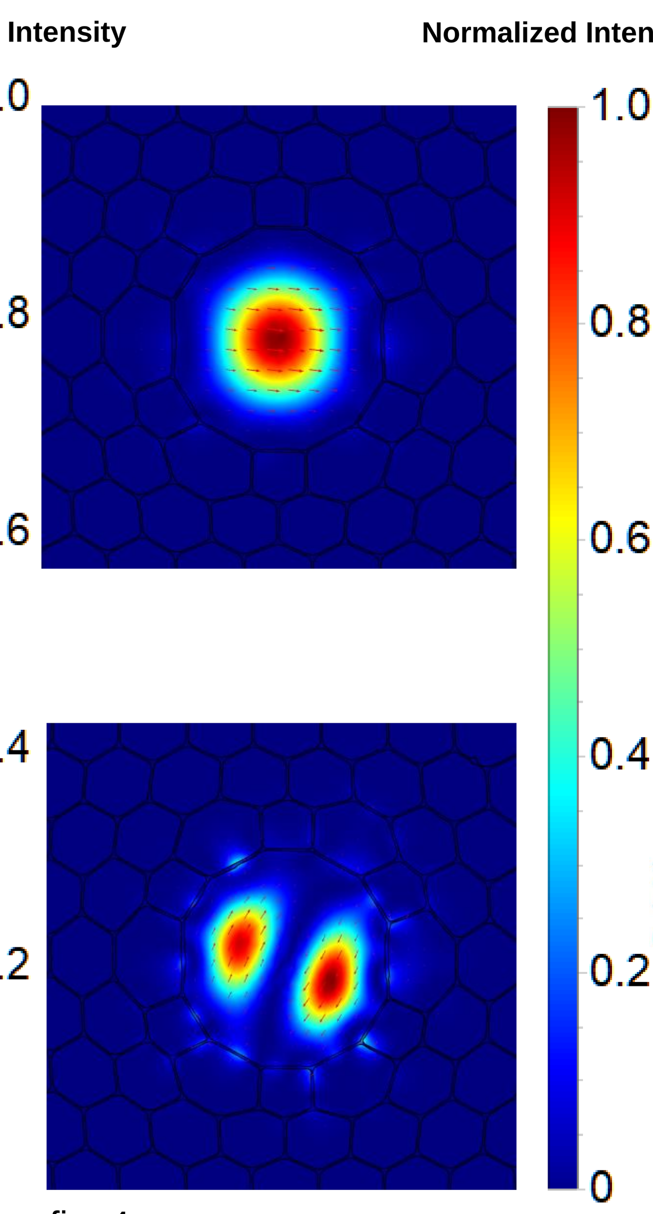


fig. 4

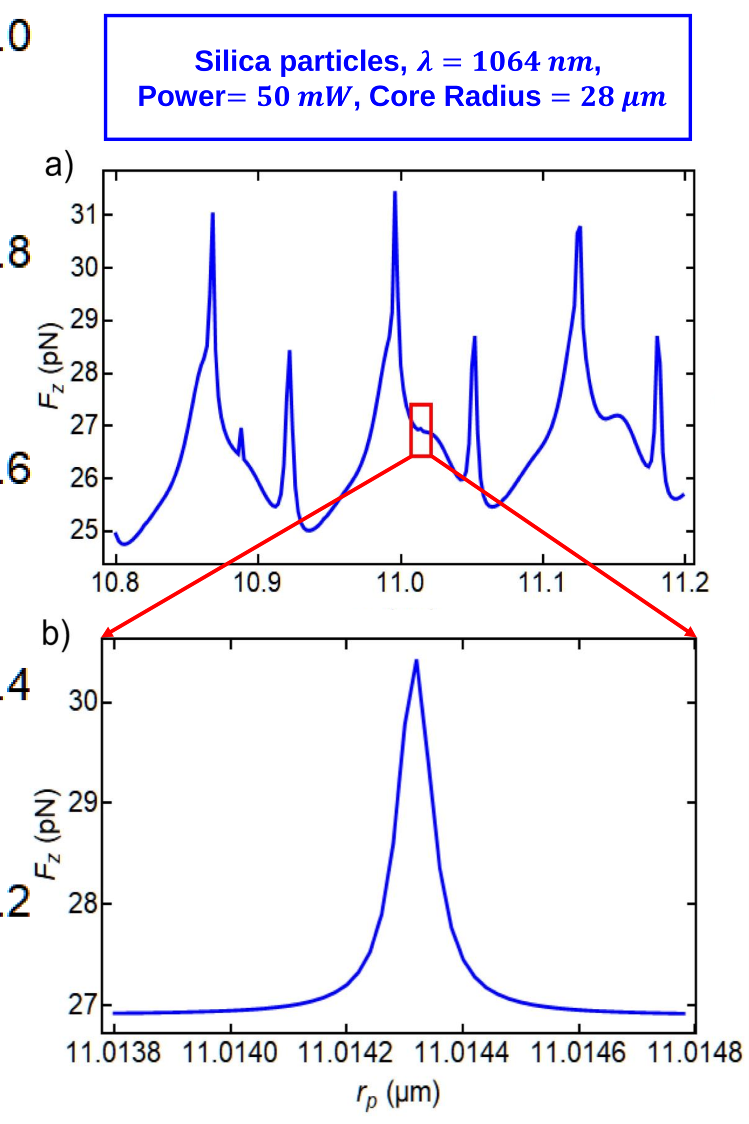


fig. 5

Trapping particles in HC-PCFs

Particles behave as probes inside HC-PCFs. A dual beam trap can be tuned through the numerical aperture of coupled beams [8]. Particles are launched through increased in-coupled optical power (fig. 6). A standing wave pattern inside the HC-PCF can obtained by counter propagating beams in the same polarization state, useful to finely control nanoparticles [9]. Multimode conveyor belts can be used to control micron-sized particles instead [10] (fig. 7).

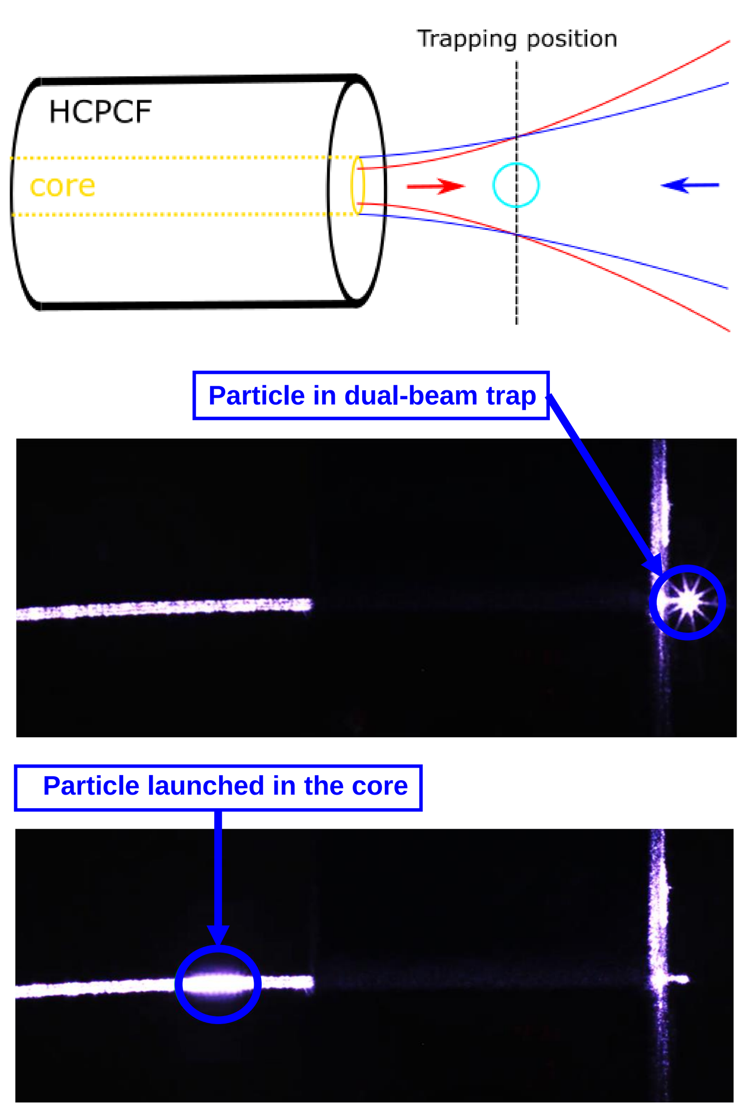


fig. 6

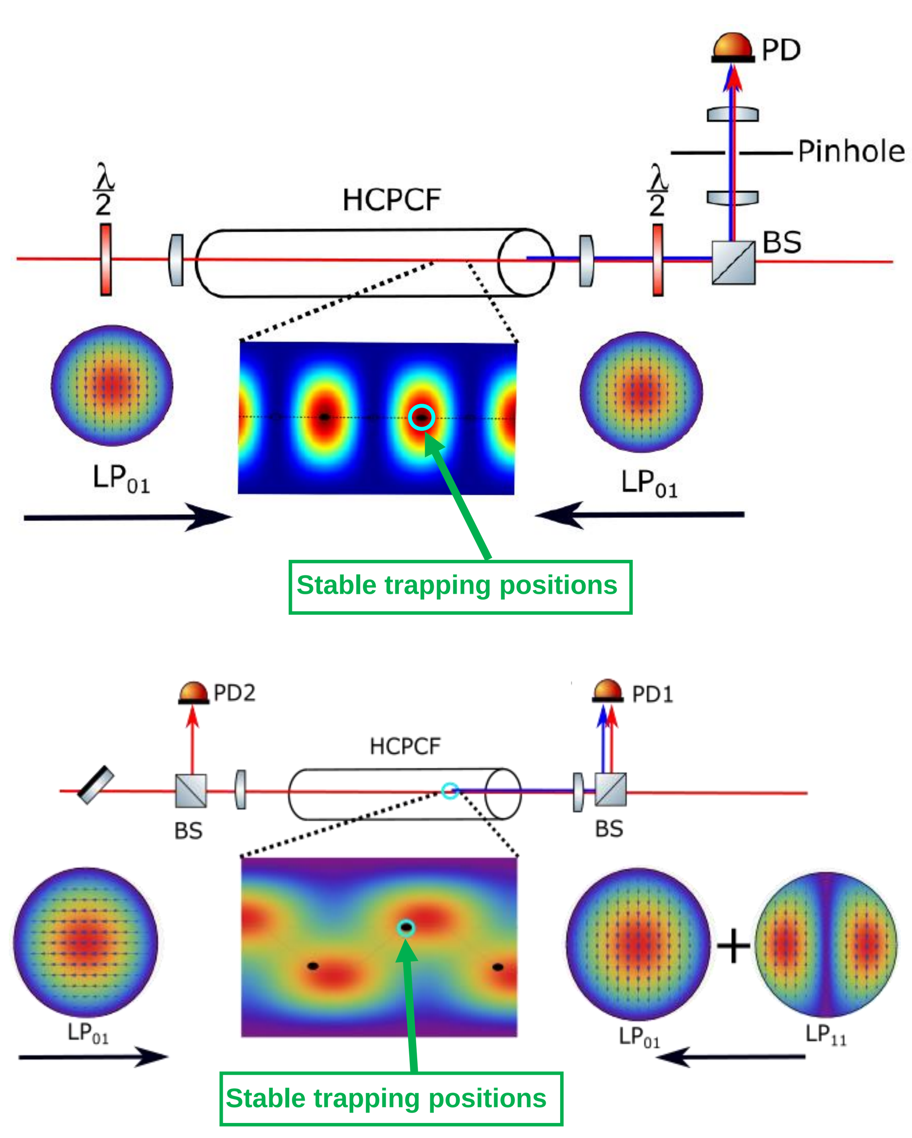


fig. 7

Measuring Temperature with HC-PCFs

Hollow core photonic crystal fibers can be used to measure temperature in a non-invasive way through the change in viscosity of air (fig. 8). In particular, the viscosity of the fluid is related to the damping of the particle motion, which can be inferred through time-of-flight experiments [11] or Brownian motion analysis.

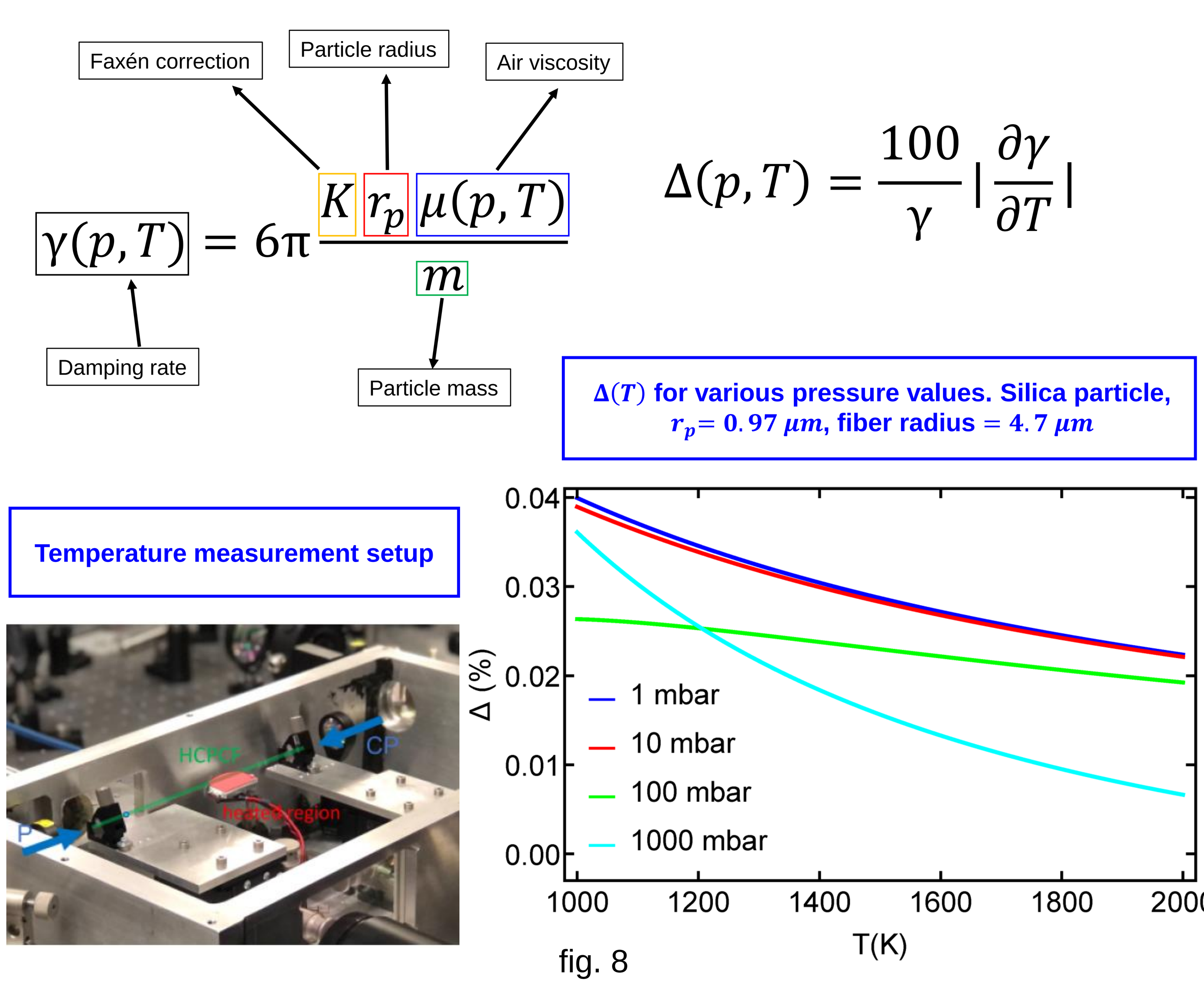


fig. 8

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