On-chip integrated silicon photonic thermometers with sub-10 uK temperature resolution

Nikolai N. Klimov, Tobias Herman, Kevin O. Douglass, Michal J. Chojnacky, Zeeshan Ahmed

National Institute of Standards and Technology, Physical Measurement Laboratory, Gaithersburg, MD 20899
nikolai.klimov@nist.gov

Temperature measurements play a crucial role in various aspects of modern technology ranging from medicine and manufacturing process control, to environmental and oil-and-gas industry. Among various temperature measurement solutions, resistance-based thermometry is a time-tested method of disseminating temperature standards[1]. Although industrial resistance thermometers can routinely measure temperatures with uncertainties of 10 mK, their performance is sensitive to multiple environmental variables such as mechanical shock, thermal stress and humidity. Drift of sensor resistance over time necessitates expensive, time-consuming recalibrations using ultra-sensitive reference thermometers and highly-specialized calibration equipment. These fundamental limitations of resistance thermometry, as well as the desire to reduce sensor ownership cost have ignited a substantial interest in the development of alternative temperature measurement solutions such as photonics-based temperature sensors. A wide variety of innovative photonic sensors have been proposed recently including functionalized dyes[2], hydrogels[3], fiber optics-based sensors[4], and silicon micro- and nanophotonic devices[5,6]. The speed and precision of optical measurements make photonic sensors an attractive alternative to traditional resistive temperature devices. Here we present the results of our efforts in developing novel on-chip integrated silicon photonic temperature sensors with nanoscale footprint and ultra-high resolution as an alternative solution to legacy-based resistance thermometers. These sensors are Fabry-Perrot cavity type silicon photonic devices that are based on photonic crystal nanobeam cavity (PhCC), whose high-Q resonant frequency mode is highly sensitive to even ultra-small temperature variations. In this talk we describe nanofabrication, fiber coupling and packaging of these thermometers, as well as their performance. We will present a direct comparison of our photonic thermometers to Standard Platinum Resistance Thermometers, the best in class resistance temperature sensors used to disseminate the International Temperature Scale of 1990. The preliminary results indicate that our PhCC nanothermometers are capable of detecting changes of temperature as small as sub-10 μK and can achieve measurement capabilities that are on-par or even better than the state-of-the-art resistance thermometry.

---

[1] Strouse, NIST Spec. Publ. 250, 81 (2008).
[2] Donner et al., Nano Lett. 12, 2107 (2012).
[3] Ahmed, J. Adv. Res. 6, 105 (2015).
[4] Kersey et al., IEEE Photonics Technol. Lett. 4, 1183 (1992).
[5] Kim et al., Opt. Express 18, 22215 (2010).
[6] Klimov et al., Proc. SPIE 9486, 948609 (2015).

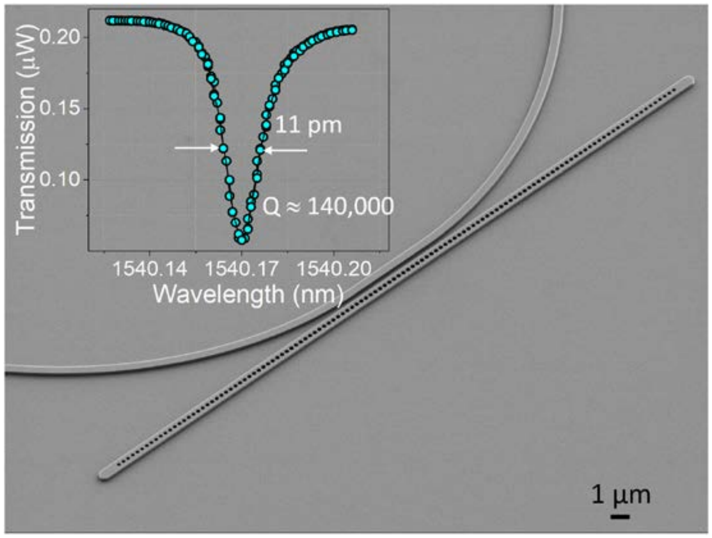

Figure 1: Silicon photonic crystal cavity (PhCC) temperature sensor: SEM image of silicon photonic nanobeam cavity temperature senor. The device is fabricated from silicon-on-insulator substrate with 220 nm thick device layer. The insert shows the resonant absorption peak of the sensor.

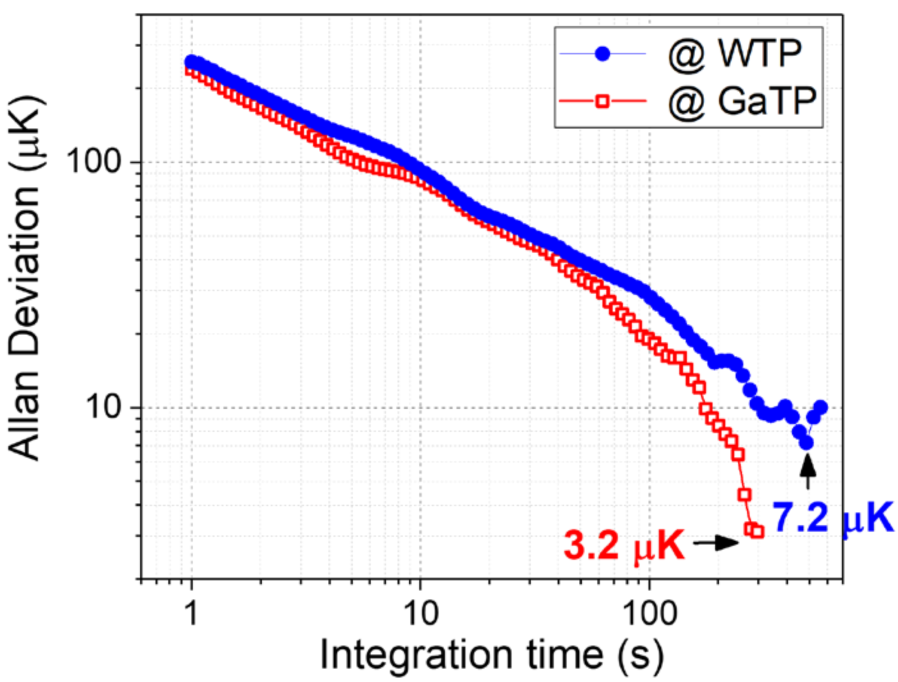

Figure 2: Temperature resolution of PhCC thermometer: Allan deviation plot of PhCC thermometer at triple point of water (WTP), blue solid circles, and triple point of gallium (GaTP), red open squares.