Supporting information

Optical Thermometry with Quantum Emitters in Hexagonal Boron Nitride

Yongliang Chen,[1] Thinh Ngoc Tran,[1] Ngoc My Hanh Duong,[1] Chi Li,[1] Milos Toth,[1,2] Carlo Bradac,[1] Igor Aharonovich,[1,2] Alexander Solntsev,[1] Toan Trong Tran[1*]

1. School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, NSW, 2007, Australia

2. ARC Center of Excellence for Transformative Meta-Optical Systems (TMOS), Faculty of Science, University of Technology Sydney, Australia

*Corresponding author: trongtoan.tran@uts.edu.au

KEYWORDS: optical thermometry, temperature sensing, hexagonal boron nitride, deterministic positioning, quantum emitter, micro-circuits.

SI1. Align-transfer setup

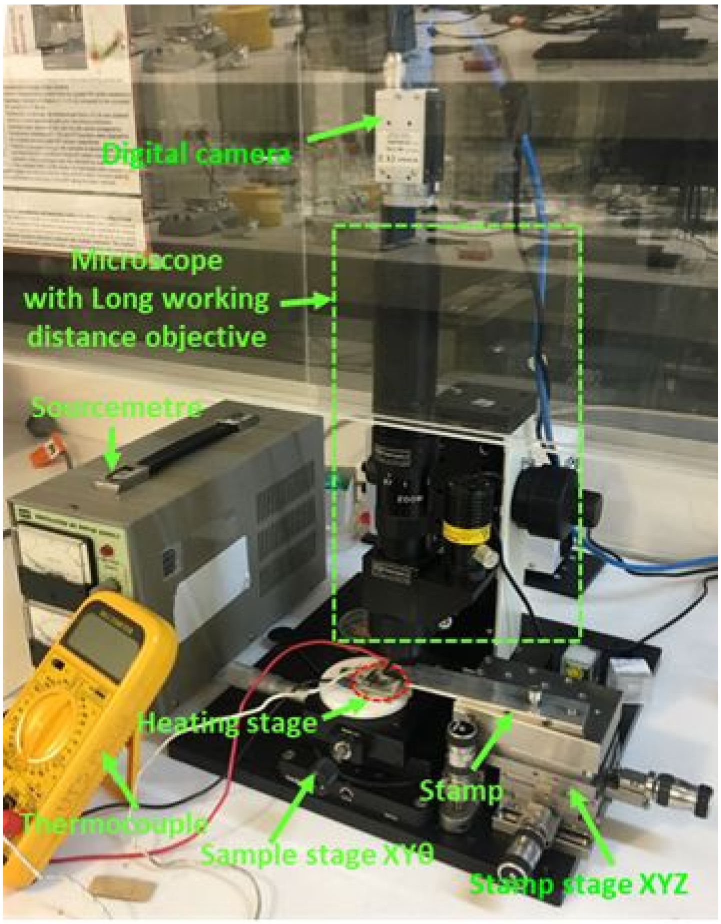


Figure S1. Photograph of the dry align-transfer setup.

SI2. Characterisation of a typical hBN quantum emitter

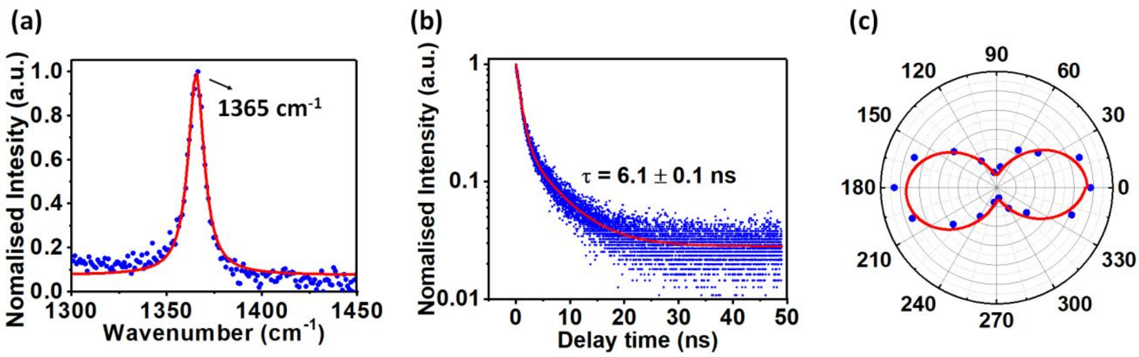


Figure S2. a) Typical Raman spectrum taken for the hBN nanothermometer in Figure 2 of the main text. The solid red trace is the fit to a single Lorentzian function. **b)** Time-resolved fluorescence measurement revealing a radiative lifetime of (6.1 ± 0.1) ns. The solid red trace is a fit to a single exponential function. **c)** Emission polarization plot of the single-photon emitter. The solid red line is a fit to a $\cos^2(\theta)$ function.

SI3. Analysis of the nanothermometer resolution

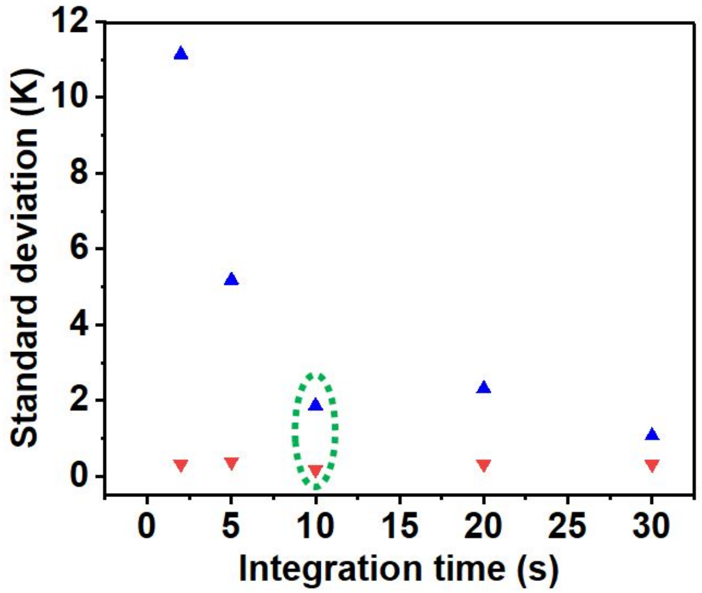
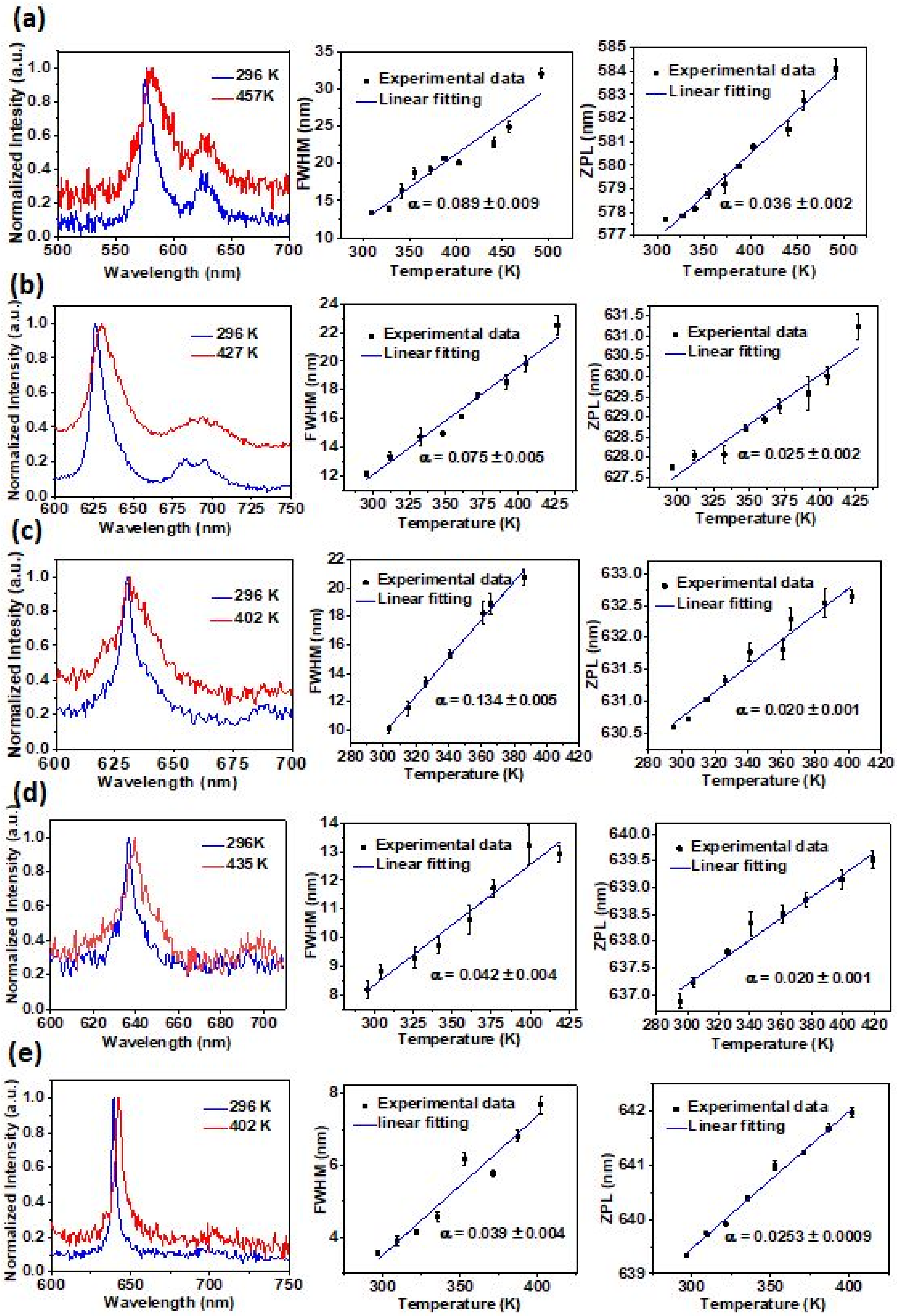
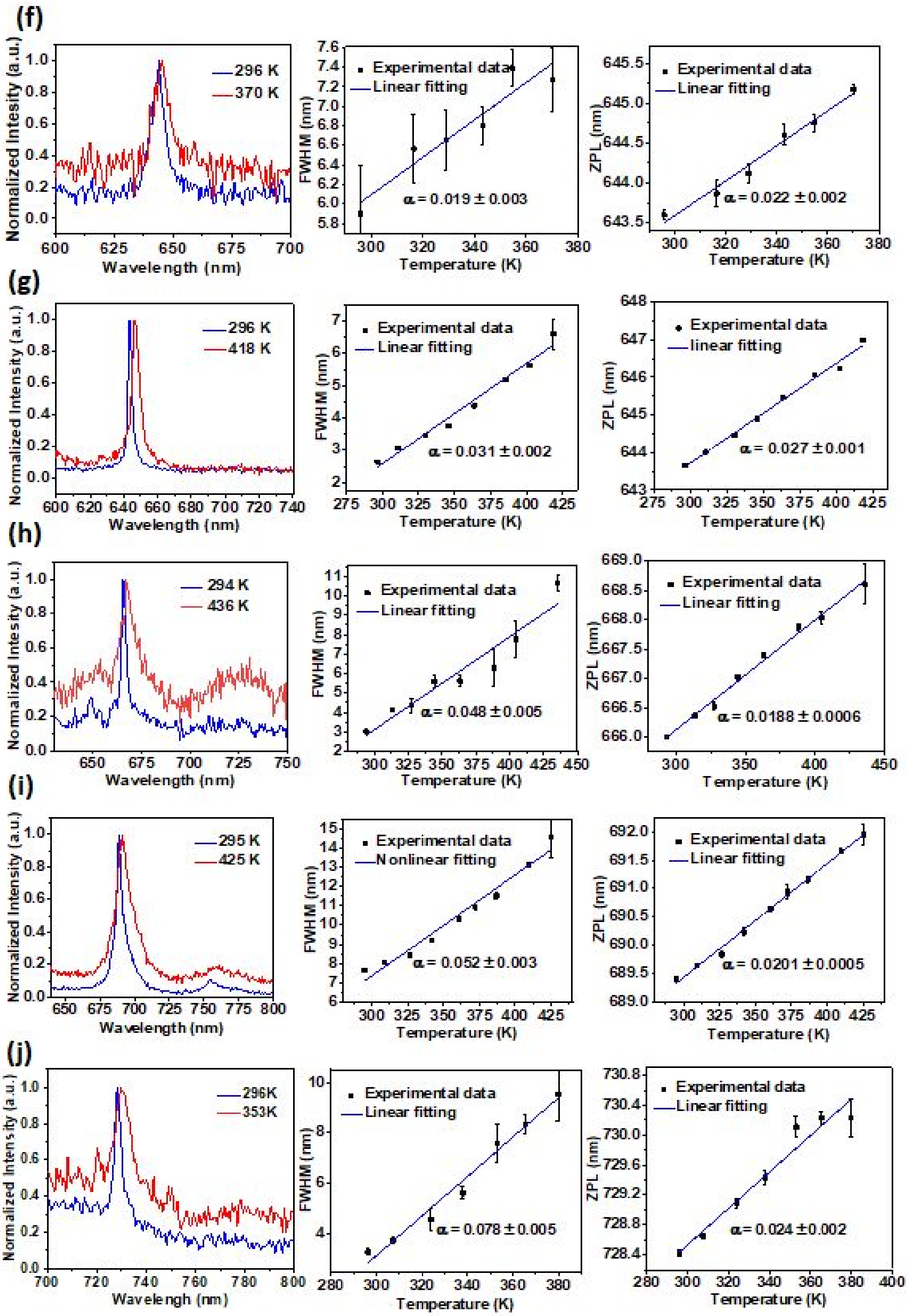


Figure S3. Temperature uncertainty at room-temperature of the hBN quantum nanothermometer Figures 3a, b, c and d in the main text. (▲) Standard deviation for the ZPL position measured at room temperature. The acquisition was carried out using a PL confocal setup with an air objective (NA = 0.7), 500 µW of 532-nm laser power and a low-resolution spectrometer (QEPro, Ocean Optics, cf. main text, Methods). Note that the standard deviation gets smaller (i.e. the resolution increases) as the signal-to noise ratio improves due to longer integration times. (▼) Same measurement as in (a) but using a more sensitive setup: air objective (NA = 0.9), 300 µW of 532-nm laser power and a high-resolution spectrometer (Princeton Instrument Spectra Pro). As expected the signal-to-noise ratio improves leading to a higher resolution.

The green dotted circle indicates our experimental condition (10-s integration time) throughout the study, cf. main text.

SI4. hBN nanothermometers: characterization of temperature response





(f)
Normalized Intesity (a.u.)
Wavelength (nm)
296 K
370 K
Experimental data
Linear fitting
FWHM (nm)
Temperature (K)
α = 0.019 ± 0.003
ZPL (nm)
α = 0.022 ± 0.002
(g)
Normalized Intensity (a.u.)
296 K
418 K
α = 0.031 ± 0.002
linear fitting
α = 0.027 ± 0.001
(h)
294 K
436 K
α = 0.048 ± 0.005
α = 0.0188 ± 0.0006
(i)
295 K
425 K
Nonlinear fitting
α = 0.052 ± 0.003
α = 0.0201 ± 0.0005
(j)
296K
353K
Wavelengh (nm)
α = 0.078 ± 0.005
α = 0.024 ± 0.002

Figure S4. Temperature calibration of several representative hBN nanothermometers. **a–j)** Left-panels: PL spectra at two different temperatures under 532-nm excitation. Mid and right panels: corresponding linear variance of FWHM and ZPL as a function of temperature. Note that the room-temperature ZPL wavelength differs from emitter to emitter: (a) 577.6 nm, (b) 627.8 nm, (c) 630.6 nm (this emitter was as nanothermometer in position 3 in Figure 3f), (d) 636.9 nm (this emitter was as nanothermometer in position 2 in Figure 3f), (e) 639.3 nm, (f) 643.6 nm (this emitter was as nanothermometer in position 1 in Figure 3f), (g) 643.7 nm, (h) 666.1 nm (this emitter was as nanothermometer in position 1 in Figure S6), (i) 689.4 nm and (j) 728.4 nm (this emitter was as nanothermometer in Figure 3d).

SI5. Temperature measurements in working micro-circuits

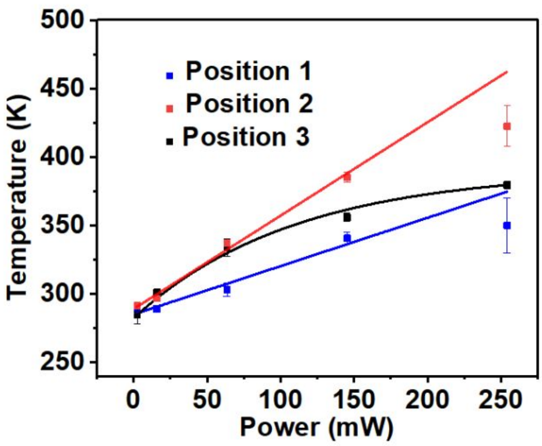


Figure S5. Relationship between temperature and power of three different positions on the studied chromium micro-circuit (cf. main text, Fig. 3f). The linear relationship with the temperature of on-circuits locations is due to the simple Joule heating phenomenon, the non-linear trend at the off-circuit location is attributed to the heat sink effect by the substrate."

SI6. Demonstration of temperature measurement on a nickel micro circuit

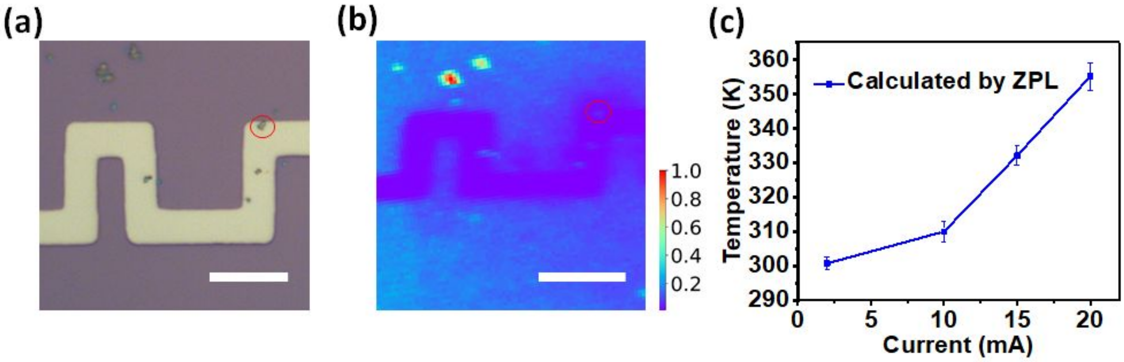


Figure S6. Temperature monitoring of a nickel micro-circuit using a hBN nanothermometer. The inset scale is 10 µm. **a)** Optical image of the nickel microcircuit made via EBL (the hBN flake is marked by the red circle). **b)** Corresponding PL confocal map. **c)** Temperature measurement from the targeted position using the ZPL wavelength shift.

SI7. Sensitivity of different hBN nanothermometers

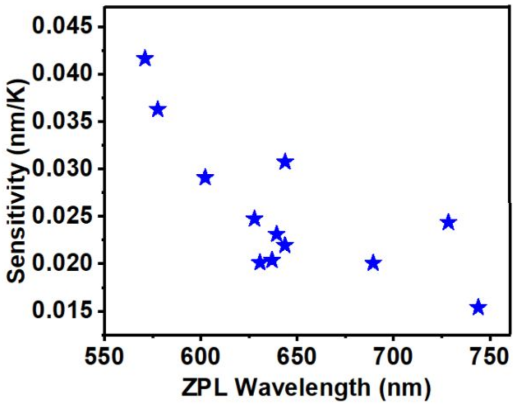


Figure S7. A summary of the sensitivities estimated as the derivative *d*ZPL/d*T* for several emitters in hBN that can be used as nanothermometers.

SI8. AFM characterisation of a hBN flake transferred onto a micro circuit

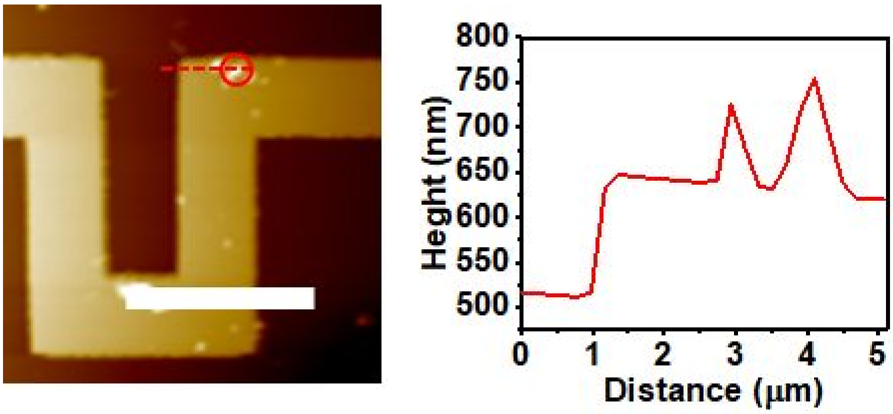


Figure S8. AFM image taken at Position 1 (cf. main text, Fig. 3) in the chromium micro-circuit used in the study. The hBN nanothermometer is ~900-nm wide and ~100-nm thick.