# Manufacture and calibration of high stiffness AFM cantilevers

Conference or Workshop Item

# Manufacture and calibration of high stiffness AFM cantilevers


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## 1. Introduction

Atomic force microscopy (AFM)[1] employs microfabricated cantilevers as sensing elements, which are used to measure surface topography and interaction forces. The flexible free end of a cantilever often presents either a pyramidal tip or a colloid probe particle. Cantilevers are traditionally V-shaped or rectangular, and are generally fabricated from Si or $Si_xN_y$. Laser light is reflected off the free end of the cantilever onto a position-sensitive photodetector (PSD). AFM force measurement studies began in earnest during the early 1990s,[2-7] followed by significant efforts to accurately calibrate the mechanical properties of the cantilever.[8-11] Efforts centred on understanding the beam mechanics, particularly the flexibility of the free end, where the tip or colloid probe is situated.

Force measurements have been applied to a wide variety of scientific and engineering disciplines, and across many industrial sectors. For many studies, the use of colloid probes or chemical functionalisation permits the selective study of a particular material/material interaction, often under non-ambient environments. Force measurements can provide information regarding sample mechanical properties, during the tip/sample approach, as well as adhesive properties, during the tip/sample separation. The spring constant is a measure of the cantilever stiffness, i.e. the resistance to bending. The spring constant of a rectangular cantilever can be estimated using Euler-Bernoulli beam theory. Once calibrated, the spring constant is used in calculations in order to convert normal (i.e. vertical) deflections into normal forces using Hooke's law.

The range of AFM cantilevers commercially manufactured means that spring constants in the approximate range $10^{-3}$ to $10^{2}$ N m$^{-1}$ are available. Deflections in the range 0.1-100 nm are typically measurable on the PSD, and hence forces can be measured in the picoNewton ($10^{-12}$ N) to microNewton ($10^{-6}$ N) range. Accurate control of the beam thickness during fabrication is particularly difficult to achieve, due to the nature of the etching process employed. The width and length of the beam are generally much more reliable and repeatable. Given the sensitivity of the spring constant to the beam thickness, typically proportional to (thickness)$^3$, accurate calibration is a necessity for accurate force measurements.

We are currently calibrating 40 different designs of rectangular AFM cantilever, illustrated in **Figure 1**, designed using Timoshenko beam theory and manufactured from Si. The cantilever designs incorporate two different nominal widths (35 µm; 50 µm), nine different lengths (100 µm to 550 µm), and two different thicknesses (12.5 µm; 25 µm), exhibiting nominal **spring constants in the range $10^2$ to $10^5$ N m$^{-1}$**.

These high stiffness cantilevers afford researchers the opportunity to utilise the displacement resolution of the AFM whilst undertaking typically-performed mechanical characterisation measurements: **adhesion, indentation, and tribological testing are now possible using normal loads approaching 1 mN**.

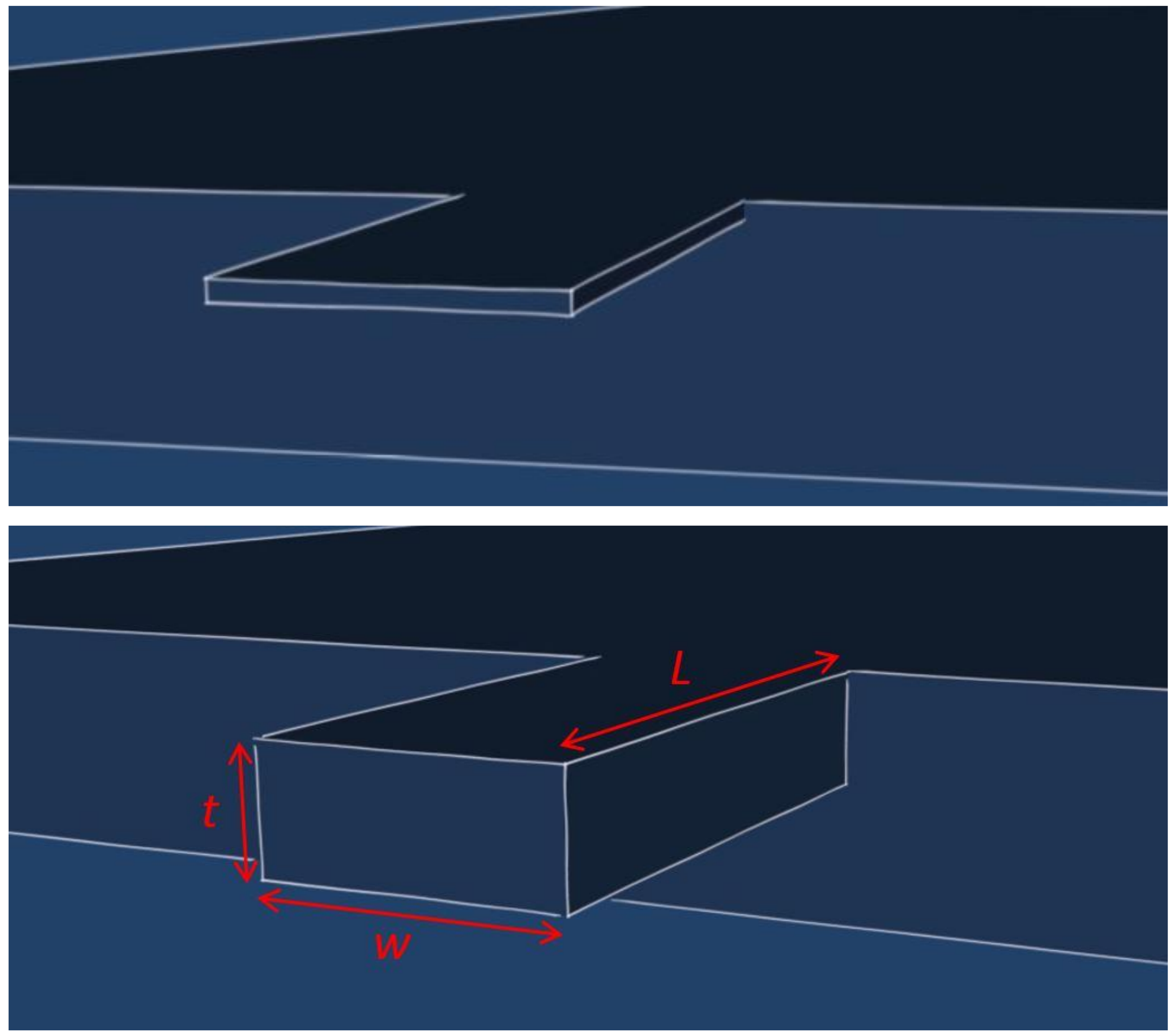


**Fig 1.** AFM cantilevers: typical design (upper); high stiffness design (lower)

## 2. Results

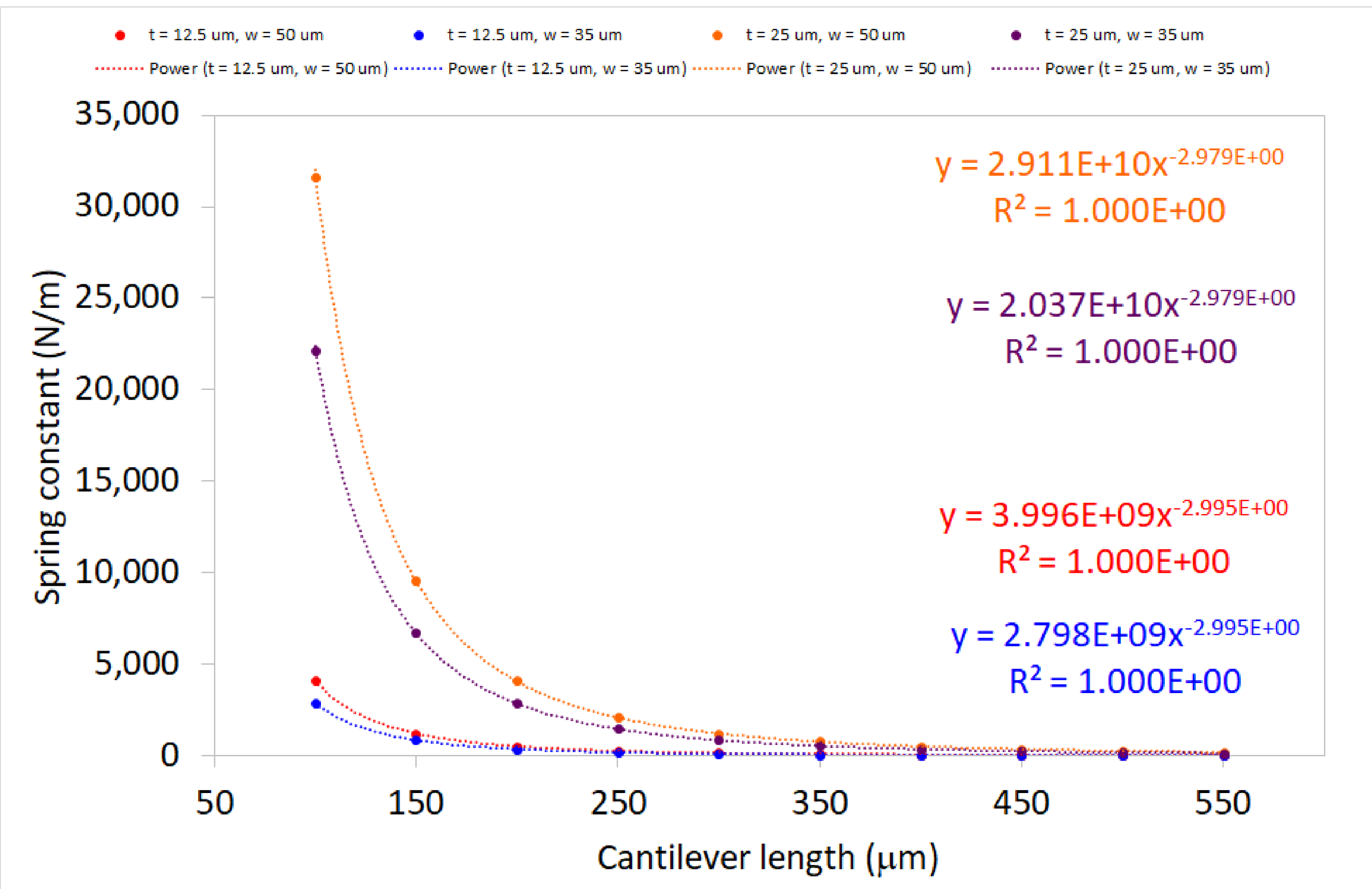


**Fig 2.** Theoretical spring constants for all cantilevers

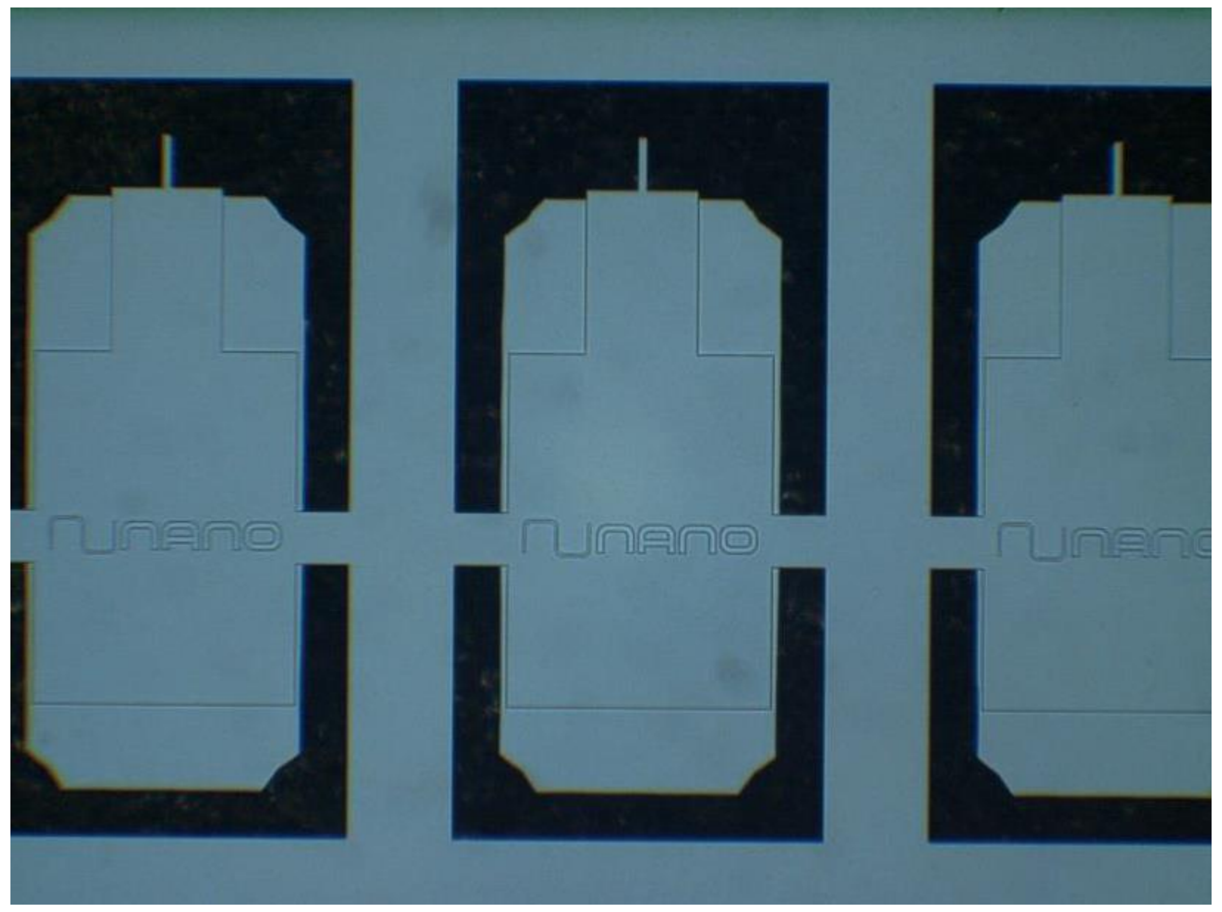


**Fig 3.** Cantilever probes as manufactured

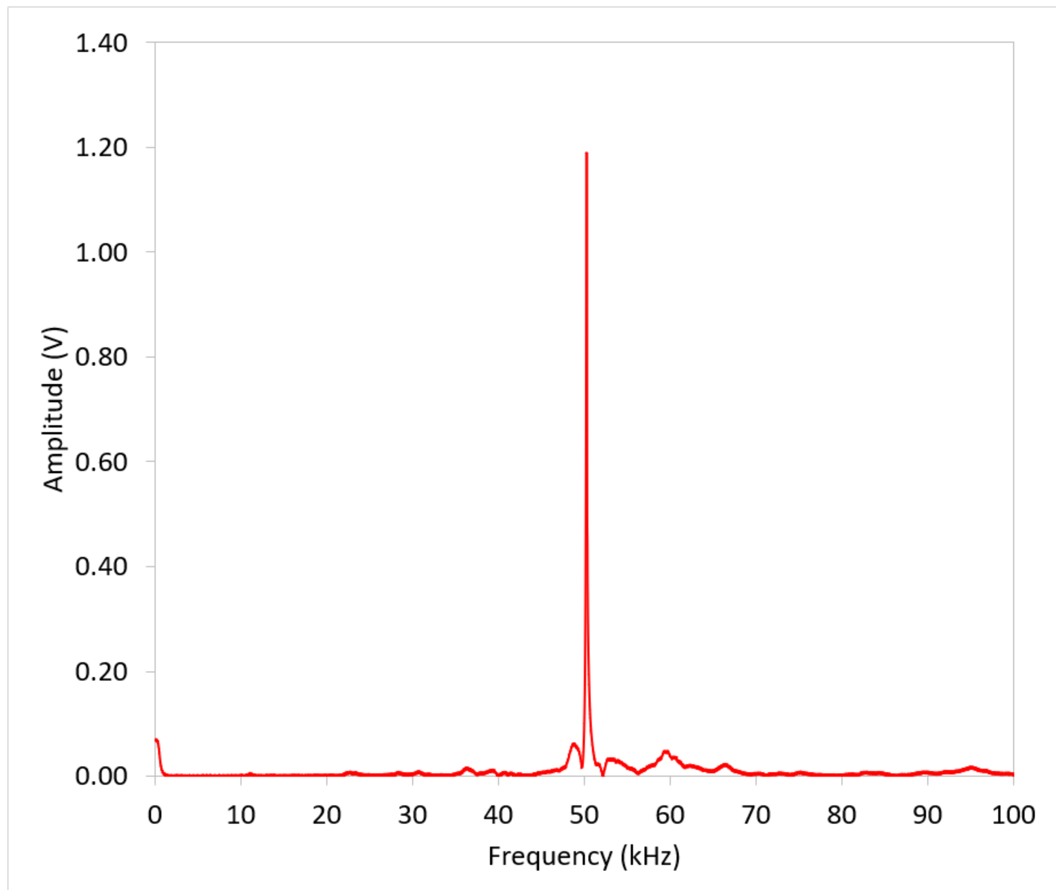


**Fig 4.** Thermal tune: $L$ = 550 µm, $w$ = 50 µm, $t$ = 12.5 µm

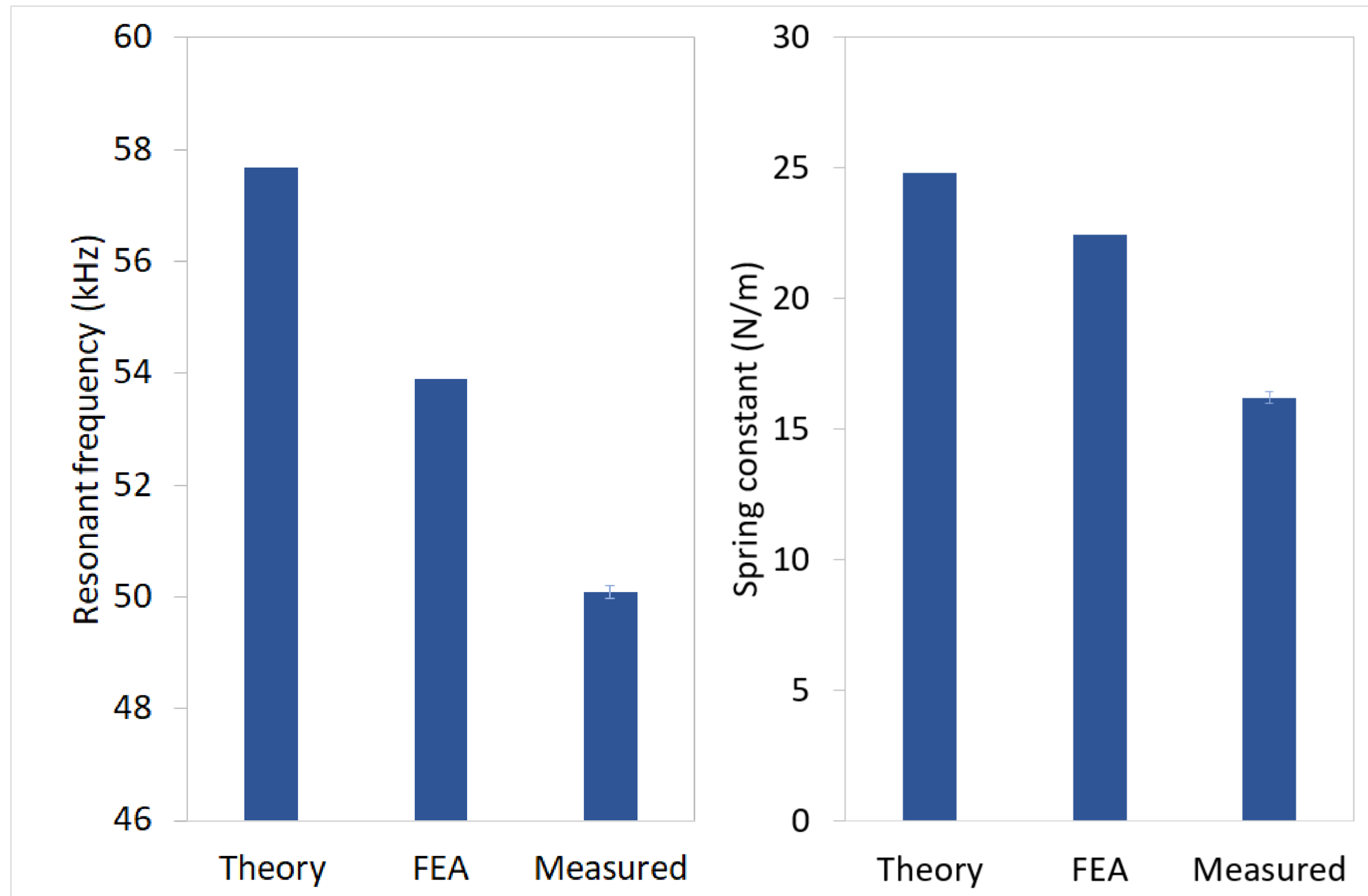


**Fig 5.** Comparing theory, finite element analysis, and measurements

## 3. Future Work

We are currently calibrating the entire range of cantilevers, comparing theory, finite element analysis, and measurement results. Given that thickness is difficult to measure, efforts will focus on accurately estimating the cantilever spring constant from the resonant frequency, assuming the length and width are known.

Preliminary studies exploring the suitability of the cantilevers for tribological testing have generated encouraging results. We are actively seeking opportunities for collaboration and innovation with materials characterisation researchers and the AFM user community.

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