Microtubules: A Potential Biological Model for Topological Phonon Edge Mode Phenomena

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Microtubules are being studied as part of a research program to develop new nanostructured materials that exhibit topological phonon modes. Analogous to topological insulators, the bulk properties of these materials cause phonon propagation along the surface or edge of the material. In the case of a microtubule, theory predicts that there is an edge mode at the tip where vibrational energy is concentrated.[1] This edge mode lies in an otherwise forbidden region of the phonon dispersion surface (i.e. the gap). Unlike topological insulators, topological phonons can be modeled with classical mechanics and physical models can be investigated by scaling up the structures. This was demonstrated by measuring an edge mode in a 2-meter-long model resembling a microtubule protofilament[2] Physical measurements are needed on the actual microtubules, but this has been difficult because of: 1) their nanoscale dimensions, 2) their elastic modulus varies as a function of their length, and 3) the ability of microtubules to drastically change their length by polymerizing or depolymerizing tubulin (the building blocks of microtubules) by a process called dynamic instability.

Another goal of the study is to understand why and how Taxol (a chemotherapy drug) affects dynamic instability. Only 1 molecule of Taxol per every 1000 molecules of tubulin can be enough to stabilize the microtubule by shifting the microtubule into a state that favors polymerization. We report studies that take the first steps to quantify the elastic properties of microtubules and the effects of Taxol as a part of studying topological phonon edge modes. We use imaging and an automated filament tracking algorithm[3] to quantify the bending modes of microtubules with and without taxol. Figure 1 shows an example of the imaging and processing used to derive sub-pixel resolution. Fourier analysis of the microtubule dynamics from the images is used to derive the amplitudes of multiple bending modes (>20) of microtubules. The derived model will be presented.

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[3] C. P. Brangwynne et al, Biophysical Journal, **93,** 346 (2007).

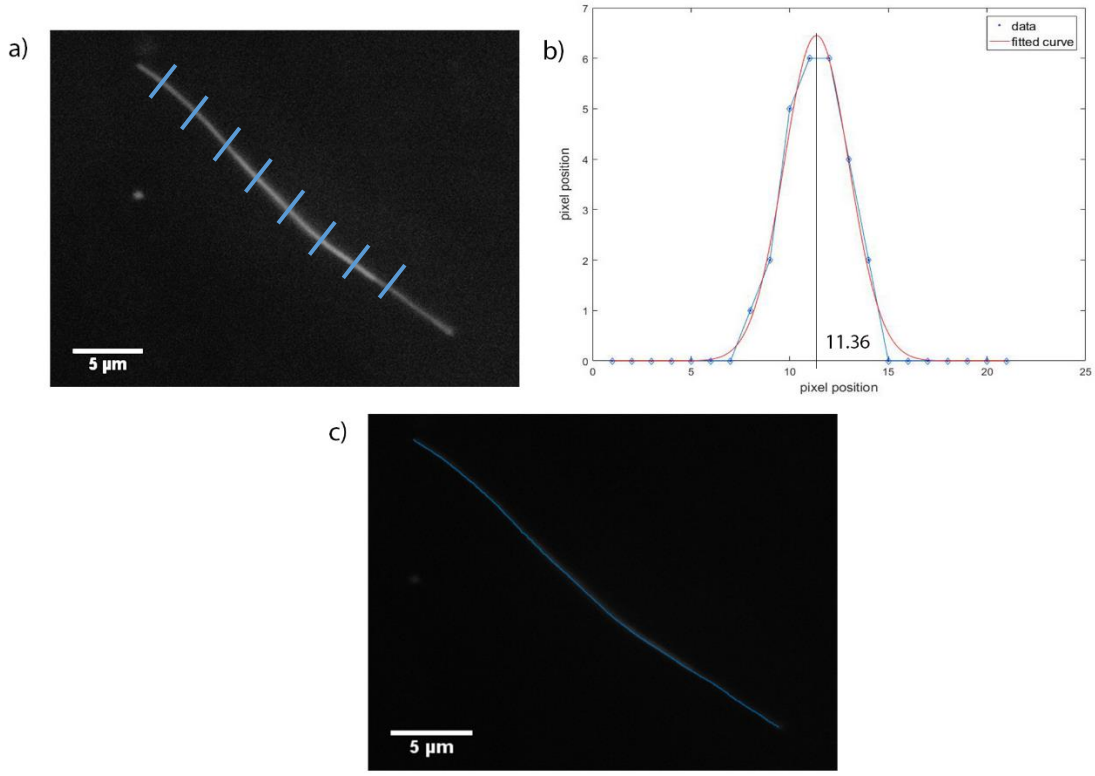

Figure 1: a) Fluorescence image of a microtubule attached to at one end. Lines represent cross-sections of the microtubule. b) Pixel intensities at the cross sections are plotted and fit to a Gaussian. The position of the Gaussian peak determines the location of the microtubule with sub-pixel resolution. c) Reconstructed microtubule. By choosing enough number of points along the microtubule and by tracking these points over time, we can measure the bending properties of the microtubule. This measurement does not assume uniformity along the microtubule, and therefore can show changes in the structural properties due to low concentrations of Taxol on regular microtubules and microtubules that have developed a resistance to Taxol.