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Converse Piezoelectricity and Ferroelectricity in Crystals of Lysozyme Protein Revealed by Piezoresponse Force Microscopy

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In recent years, piezoresponse force microscopy (PFM) has been used to investigate the piezoelectric and ferroelectric behaviour of many biological materials. Piezoelectricity has been studied in fibrous proteins such as collagen [1, 2] and elastin [3], with the later also demonstrating ferroelectricity. However, a comprehensive understanding of piezoelectricity and ferroelectricity in *non-fibrous proteins* is lacking.

In the classical sense, piezoelectricity can only occur in materials with a non-centrosymmetric structure. It is not known whether this classical theory of piezoelectricity applies to protein piezoelectricity. As non-fibrous proteins can be crystallized, they present a unique perspective from which to address these questions. Such studies have not been realized to date, perhaps because of the challenges associated with electroding fragile protein crystals while maintaining their hydration. Here, we grow crystals of the globular protein lysozyme within a film. PFM in both contact mode and hybrid mode were used to investigate if lysozyme crystals demonstrate the converse piezoelectric effect. Hybrid PFM was employed to map the mechanical properties of lysozyme crystals at the surface. Ferroelectricity in lysozyme crystals was also detected by switching-spectroscopy PFM (SS-PFM). We explain these findings using crystallographic principles and propose that the presence of defects within the crystal may lower the symmetry of lysozyme to a polar one. Our findings point towards the potential of exploiting lysozyme and other proteins in technical applications, especially those in which biocompatibility is critical.

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1. M. Minary-Jolandan, M.F. Yu, *Nanotechnology*, **20**, 8 (2009).
2. D. Denning et al., *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, **102**, 2 (2014).
3. Y. Liu et al., *Proceedings of the National Academy of Sciences*, **111**, 27 (2014).