Imaging a sample spinning at 30 kHz and more: A new horizon for solid-state MRI

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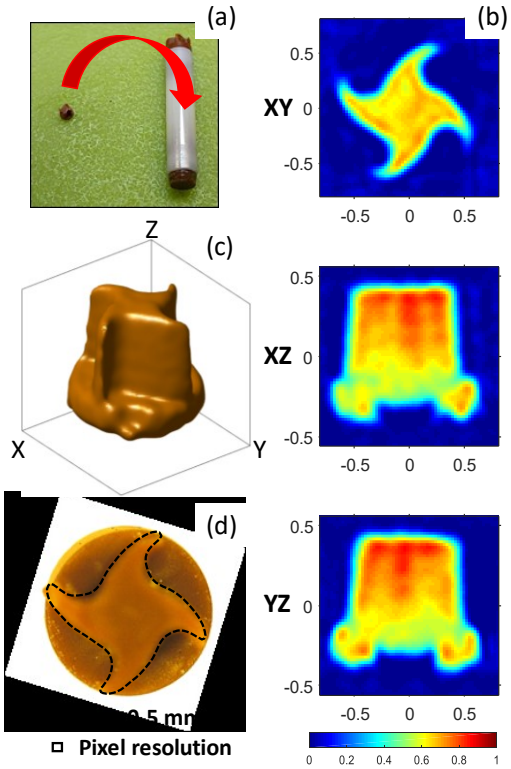
Introduction: Fifty years after its proof of concept [1], magnetic resonance imaging has become a gold standard technique to produce high quality images of water in soft tissues. Even today, thousands of scientific articles involving MRI are published annually, and a significant part of them are related to new methodologies (hardware, sources of contrast, metabolism, acquisition schemes and data processing) showing the vitality of this field of research. At the same time, there are far fewer publications on MRI of solids (less than a thousand), but not because of a lack of interest. Indeed, the anisotropic NMR interactions (dipolar, quadrupolar, chemical shift) that remain in the solid state are responsible for very short transverse relaxation times and strong line broadening which are deleterious for sensitivity and spatial resolution. Several strategies for MRI of solids have been proposed [2], but the current methods consist in encoding the k-space as soon as possible with strong magnetic field gradients [3]. Another approach directly derived from solid-state NMR spectroscopy is the well-known magic angle spinning (MAS) technique leading to narrowed lines and increased relaxation times, hence enhancing the sensitivity and the spatial resolution. As the object of interest is rotating, synchronization of the spatial encoding direction is performed by generating oscillating gradient shapes from a 3D axis system. This method has proved relevant capabilities for MRI of solids for moderate MAS frequencies (10 kHz) [4]. For materials with strongly coupled spin systems (homonuclear dipolar or quadrupolar couplings), it is necessary to spin the sample at very fast MAS frequencies (>30 kHz). Unfortunately, the induction of the gradient coil makes it very difficult to generate accurate oscillating gradients. In this work, we demonstrate that it also possible to obtain well-resolved images of solids at very fast MAS frequencies using simply a steady gradient. To this end, the implementation of a multiple-pulse sequence is required to sample the k-space similarly to standard MRI. This new methodology is illustrated experimentally with different solids samples exhibiting strong couplings (e.g. 1H-1H). We also focus that it gives an opportunity to convert your NMR spectrometer in a MRI scanner for free.



(a) Picture of a 1.3 mm drive cap before its wedging inside a 2.5 mm MAS rotor. (b) Three orthogonal slices (XY, XZ, YZ) in the rotor frame of the 1.3 mm drive cap obtained at a **spinning frequency 30 kHz**, and using the MAS-MRI-SF2 sequence (N = 12, I = 24). FOV(ZXY) = 1.1×1.6×1.6 mm^3 ; **spatial resolution (ZXY) = 50×84×84 µm^3**; scale in mm. (c) 3D isosurface of the drive cap (isosurface level = 40%). (d) Top view of the drive cap.

References:

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[3] Weiger M., Pruessmann K.P., Prog. Nucl. Magn. Reson. Spect., (2019) 114–115:237.
[4] Yon M., Sarou-Kanian V., Scheler U., Bouler J.-M., Bujoli B., Massiot D., Fayon F., Sci. Rep. (2017) 7:8224.