Shaking Surfaces: Investigating Crystalline Solids with Focused Ultrasound

Ben Messerly, 2011

According to the elastic continuum theory of solids, when atoms of a crystal are displaced from their equilibrium position, the inter-atomic bonds of the surrounding atoms provide forces that restore the displaced atom back towards equilibrium. The atoms, their bonds, and the restoring forces can be modeled as tiny masses connected to springs, which obey Hooke’s law of elasticity – hence the “elastic” of elastic continuum theory.

Crystals are anisotropic materials, which means that their inter-atomic bond strengths are directionally dependent. These anisotropies cause vibrational waves moving on or in a crystal to travel at different speeds along different directions. For example, while a disturbance on the surface of an isotropic material or fluid such as water will produce circular wave patterns – the wave speeds being equal in all directions – a disturbance on the surface of an anisotropic crystal will produce wave patterns of other shapes – a result of directional dependent wave speeds.

The goal of my research this summer was to image various crystals’ directional dependent surface wave speeds and compare them to computer models based on three-dimensional formulations of Hooke’s law. This sort of ultrasound imaging and analysis is used to learn more about the intrinsic nature of materials. Also, it is a primary technique of what is called Nondestructive Evaluation (NDE). Engineering and technology groups such as NASA are interested in how various materials perform under extreme conditions like outer space, and ultrasound imaging serves as a non-invasive inspection technique.

To image surface wave speeds, sound pulses are first sent from a focusing ultrasound transducer to create a point disturbance on the crystal. Vibrational waves caused by the disturbance then travel along the surface to be picked up by an opposite, receiving transducer. The receiving transducer measures the strength of the waves and the time of arrival. Knowing the time of arrival and the distance of surface propagation, the wave speeds can be found.

High quality images of silicon and calcium tungstate were taken (see Fig. 1) and they match first computational models developed by Vines. Current work incorporates the effects of surface water loading, which accounts for the fact that the experiment is completely submerged in water.

Having obtained high quality surface velocity data, future work will likely split into two parts: first, computer models can be improved to incorporate water loading and other boundary effects. And second, we can work toward imaging waves through the bulk of crystals, which incorporates a new apparatus.

Fig. 1 Angle-time images showing surface wave arrival on a) silicon and b) calcium tungstate.

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