Atomic force microscopy - what is it all about, and what does it tell us about the microstructure of metals?

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Atomic force microscopy (AFM) is a near-field technique to generate high-resolution images of surfaces while they are scanned with a sharp sensor tip integrated at the end of a microfabricated elastic beam. In conventional AFM, the deflection or torsion angle of the cantilever beam is kept constant while scanning in order to image topography or friction, respectively. A variety of dynamic AFM operation modes such as e.g. force modulation microscopy, ultrasonic force microscopy, scanning local acceleration microscopy or pulsed force microscopy allow to generate images the contrast of which depend on the local elasticity. Conventional AFM cantilevers are fabricated in one piece with the chip by etching out of silicon single crystals. The small elastic beams have a length of a few 100 µm, a width of a few 10 µm, and a thickness of a few µm. These properties entail vibration resonances in the ultrasonic frequency range, i.e. AFM cantilevers are usable as near field ultrasonic probes. The integrated sensor tip is about 10 to 15 µm long, the radius at its end is a few nm up to of a few 100 nm and defines the accessible spatial resolution. Dynamic AFM operation modes with ultrasonic frequencies exploit flexural and torsional vibration resonances of the cantilevers. In tapping mode, free resonances are used for topography imaging. Contact resonance AFM such as e.g. atomic force acoustic microscopy (AFAM), ultrasonic friction force microscopy (UFFM), magnetic force microscopy (MFM), and ultrasonic piezo-mode (UPM) exploit the change in resonance frequencies by contact forces between the tip and a sample surface. Some of the methods require special sensor tips, e.g. electrically conductive ones for UPM and with a magnetic coating for MFM. Convenient contact models are used for quantitative evaluation of the frequency shifts to determine local sample surface properties. In short, AFM with all its different operation modes is a powerful tool for microstructure imaging and local materials characterization of surfaces with a spatial resolution down to the nm range. Thus it can be used to reveal correlations between the micro- and nanostructure and macroscopic materials behaviour paving the way for materials design.

New design concepts for the construction of advanced light-weight and crash resistant transportation systems require the development of high strength and supra-ductile steels with enhanced energy absorption and reduced specific weight. TWIP (Twinning Induced Plasticity) steels have excellent mechanical properties combining high strength levels with a large uniform elongation. This is caused by intensive mechanical twinning resulting in a high sustained degree of strain-hardening. Investigations of the mechanisms and the related microstructures are shown. Cementite (Fe₃C) is a very important phase in steels because its morphology directly controls the macroscopic mechanical properties. The cementite phase embedded in a ferrite matrix is characterized by Atomic Force Acoustic Microscopy (AFAM) and nanoindentation studies. Magnetic force microscopy (MFM) coupled with an external coil providing an in-plane controlled magnetic field is employed to image the dynamic behaviour of the magnetic domains in the cementite precipitates as well as the ferrite matrix of unalloyed steels. Furthermore results on nanostructured nickel samples are presented.

Keywords: atomic force microscopy (AFM), atomic force acoustic microscopy (AFAM), contact resonance, dynamic operation modes, imaging, magnetic force microscopy (MFM), microstructure, nanostructure, near-field, piezo-mode, quantitative evaluation, ultrasound, metals