Atomic imaging of NiO with nonmagnetic, ferromagnetic and antiferromagnetic tips

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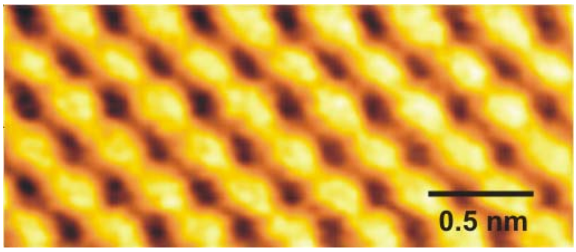
Spin-polarized scanning tunneling microscopy allows direct imaging of the opposite spins in antiferromagnets [1]. In principle, atomic force microscopy (AFM) should also allow atomic imaging of antiferromagnetism due to the contribution of the exchange interaction to the tip-sample-force. With this aim, NiO (001), a room temperature antiferromagnet (T_N = 525 K), has been investigated by several groups [2-4]. However, a clear-cut proof of imaging spin contrast using AFM is lacking so far. Calculations show that the exchange force caused by antiferromagnetic coupling of the spins has an extremely short range [5] and only appears for tip-sample distances close to mechanical contact. Non-destructive atomic imaging in an intermittent contact regime is possible by small amplitude AFM, requiring stiff cantilevers for stability. We therefore investigated the NiO (001) surface with a novel extra stiff qPlus sensor ($k \approx 4000$ N/m) that allowed imaging with sub-Å amplitudes. Three different tip materials were used to study the influence of magnetic coupling between tip and sample: a W-wire (nonmagnetic), a Co-wire (magnetized || (001)) and a sharply pointed chip of NiO (antiferromagnetic) (Fig. a)). All tips showed atomic contrast in constant-height and topographic measurements. Atomic imaging in various distance ranges was performed, including the repulsive regime (Fig. b)). While the tip-sample distance was short enough to probe the theoretically expected exchange force contributions, none of the experimental data has shown antiferromagnetic order. The force over neighbouring atoms with opposite spin is expected to be of the order of $F \approx 100$ pN [6] – ten times larger than the estimated experimental noise level of $\delta F \approx 10$ pN. Possible reasons for the lack of spin contrast will be discussed.

a) Sensors with W-, Co- and NiO-tip;
Insets: tips magnified ~ 4x



b) NiO (001) surface imaged with a NiO-tip at $\Delta f = +30$ Hz

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