MAX-PHASE FILMS AS HEAT SINKS FOR HEAT-ASSISTED MAGNETIC RECORDING

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I. MAX PHASES AND MXENES

MAX phases are inherently nanolaminated materials, which are composed of an early transition metal M, an A-group element A, and either C or N, denoted X. All known MAX phases have a layered hexagonal structure with P63/mmc symmetry. The compounds with chemical formula $M_{n+1}AX_n$ (n = 1-3) are electrically and thermally conductive, lightweight, stiff, resistive against oxidation [1] and can show self-healing properties [2]. M_2AX_1 phases consist of M-X-M (quasi 2D) atomic layers stacking in the c-direction with an A-element spacer. Significant interest to MAX phase systems is due to its machinability and the recently discovered possibility of delamination of layered MAX phase structures. The latter leads to 2D graphene-like MX materials with strong chemical bonds [3]. These systems, so-called MXenes, show exceptional properties important for catalysis and energy storage applications [3,4].

We measured the electrical conductivity of 13 nm thick Ti_3C_2 MXene thin films on glass substrate as function of H and O plasma treatment and as function of humidity [5]. It turns out that the resistivity can be switched reproducibly by plasma treatment between 5.6 μΩm (oxidized state) to 4.6 μΩm (reduced state). Both states show metallic conductivity. Moreover, we found a 26-fold increase of the resistivity at relative humidity of 80% as compared to high vacuum conditions [5] leading to possible sensing applications.

II. MAX PHASE FILMS AS HEAT SINKS

Recent studies have shown that MAX phases exhibit unusual and exceptional mechanical, electrical, thermal and chemical properties. They are electrically and thermally conductive due to their metallic-like nature of bonding. The key properties of the MAX phases for their use as heat sink layers are their anisotropic thermal and electrical conductivities [6]. The electrical and (presumably) the thermal conductivities in the direction parallel to the c-axis of the hexagonal compounds are 1000 to 10000 times smaller with respect to the conductivities within the M-X-M basal planes. Due to the orientation of the epitaxial MAX phase film and its 2D character lateral heat transfer is faster as compared to isotropic systems. Such ‘thermal anisotropy’ is superior where fast dissipation is needed and the thermal profile shall be sharpened. One example is heat-assisted magnetic recording (HAMR) [7]. We present first results on the anisotropic thermal conductivity for MAX phase films as determined from 3ω measurements [8].

III. MAGNETIC MAX PHASE FILMS

In 2013, the new class of magnetic MAX phases were discovered which contain Mn or a mixture of Cr and Mn as the M element. Ternary Mn_2GaC and quaternary $(Cr_{0.5}Mn_{0.5})_2GaC$ magnetic compounds have been synthesized as hetero-epitaxial films [9,10]. Magnetometry and ferromagnetic resonance (FMR) reveal ferromagnetic (FM) properties of $(Cr_{0.5}Mn_{0.5})_2GaC$ at temperatures below 220 K. The saturation magnetization is on the order of 0.7 μ_B per M-atom and soft magnetic properties possessing small c-axis magnetocrystalline anisotropy energy density (MAE) below 5 kJ/m^3. Negative magnetoresistance of about 5% has been found originating from spin-dependent scattering of electrical charge carriers.

Following material stability calculations, the Mn_2GaC MAX phase compound has recently been synthesized [11]. A comprehensive study of magnetic phase transitions in the Mn_2GaC films has been undertaken [9]. The material exhibits two magnetic phase transitions. The Néel temperature is $T_N \approx 507$ K, at which the system changes from a collinear AFM state to the paramagnetic state. At T_t = 214 K the material undergoes a first order phase transition from AFM above T_t at higher temperature to a non-collinear AFM spin structure. Both states show large uniaxial c-axis magnetostriction of 450 ppm. Remarkably, the magnetostriction changes sign, being compressive (negative) above T_t and tensile (positive) below the T_t. The sign change of the magnetostriction coefficient across the phase transition is a fundamentally new property, which we ascribe to the layered structure and competing antiferromagnetic and ferromagnetic exchange interactions between magnetic atomic layers. The sign change of the magnetostriction is accompanied by a sign change in the magnetoresistance indicating a coupling between the spin, lattice and electrical transport properties in this system [9].

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