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Modification of magnetic properties of Pt/Co/Pt trilayer under nanosecond EUV irradiation

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Ion bombardment driven transition from perpendicular to in-plane magnetization state was investigated since fifteen years, see e.g. [1]. It has been lately shown [2,3] that 30 keV Ga+ ion irradiation can induce transitions from in-plane to out-of-plane state (PMA) of magnetic anisotropy in Pt/Co/Pt thin trilayers. Similar behavior has been very recently reported for femtosecond pulse laser irradiation in [4]. PMA creation we have also found by using extreme ultraviolet EUV pulses. The purpose of the current work is a study of relation between structural and magnetic changes in Pt/Co/Pt under EUV light irradiation and understand a mechanics of observed transitions.

Trilayers with a structure of (substrate-Al2O3(00.1))/(Pt(111) 5 nm)/(Co(00.1) 3 nm)/(Pt(111) 5 nm) were epitaxially grown with MBE technique in UHV conditions. As grown samples have smooth surface and in-plane magnetic anisotropy.

A laser-plasma extreme ultraviolet (EUV) source is based on a double-stream gas puff target created in a vacuum chamber synchronously with the pumping laser pulse [5]. The target is formed by pulsed injection of a Kr Xe gas mixture into a hollow stream of helium. The gas puff target is irradiated with 3ns Nd:YAG (λ=1.06 μm) laser pulses with energy of 0.8J and repetition rate of 10 Hz. The EUV radiation is focused using a grazing incidence gold-plated ellipsoidal collector. Spectrum of the reflected radiation consists of a narrow feature with intensity maximum at 10–11 nm wavelength and a long-wavelength spectral tail up to 70 nm. As a result this EUV source was capable to irradiate in vacuum a sample with single/multiple pulses with energy density up to 100 mJ/cm^2 and duration about 3 ns. Radial distribution of energy density $\sigma(x)$ is shown in Figure 1.

After irradiation in vacuum with single EUV pulse we observed the appearance of spot with out-of-plane magnetization visible in remanence polar magneto-optical Kerr (PMOKE) images (Figure 2).

Bright black ring corresponds to PMA region, but inside spot magnetization is in-plane. Using calibration curve from Figure 1 we obtain that PMA state corresponds to irradiation energy density from 60 to 75 mJ/cm^2, but above this value magnetization returns to in-plane state.

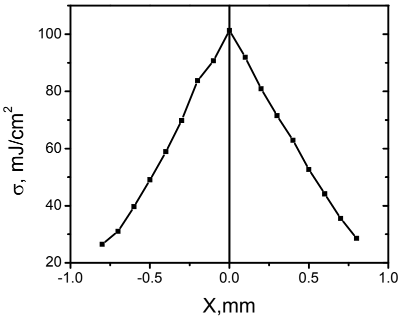

Figure 1. . Radial distribution of energy density for EUV source measured with pin-hole detector.

Detailed atomic force microscopy (AFM) imaging of the center of the irradiated stop revealed the appearance of micrometer range holes (Figure 3). These holes penetrate entire metallic trilayer down to substrate. The appearance of the holes in the metallic films under nanosecond laser pulses is explained with beginning of the film dewetting [6], i.e. transition of film to liquid state.

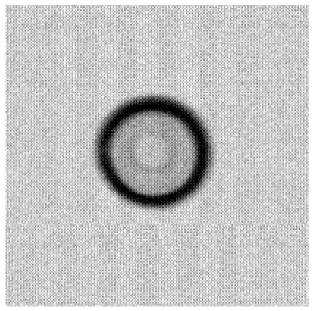

Figure 2. PMOKE remanence image of irradiated spot. Image size 2x2 mm^2.

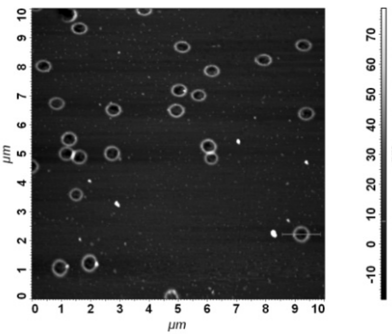

Figure 3. AFM image of the black interior inside irradiated spot.

Magnetic force microscopy (MFM) reveals tiny domain structure in irradiated spots. In Figure 4 we see MFM image at the boundary between in-plane central circle (left) and PMA ring (right). In PMA region the sizes of magnetic domain are about 2 μm and quickly reduced to zero for in-plane region. The transition is very sharp (order of 2 μm) while at outer boundary it is more then ten times blurred.

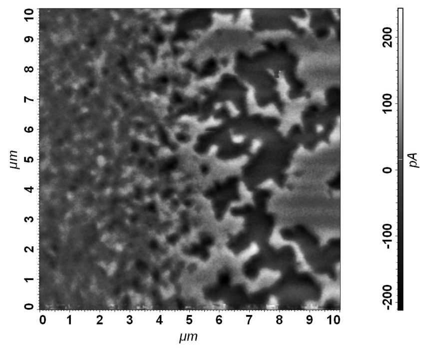

Figure 4. MFM image at the boundary of central black interior (left) and white ring (right).

Using PMOKE image processing techniques we have measured the dependence of magnetic parameters (maximal Kerr rotation, remanence, coercivity) as a functions of distance from the spot center. As an example, the dependence of Kerr rotation remanence $\theta_{REM}(r)$ is shown in Figure 5. The difference in sharpness of transition for internal boundary between MFM (Figure 4) can be attributing to the dithering of irradiation energy density on azimuth angle and averaging of PMOKE results for entire ring of constant radius.

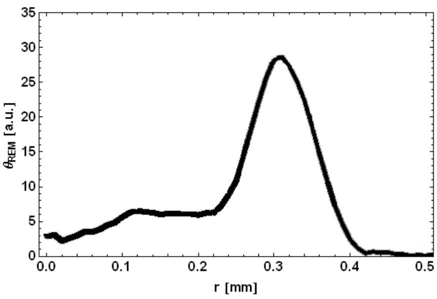

Figure 5. Radial dependence of Kerr rotation remanence θ_{REM}.

For structural XRD measurements we have prepared big sample (5x5 mm^2) with quasi-uniform (stop-by-spot) irradiation with a energy density corresponding to the PMA region. The appearance after irradiation of the strong diffraction peak can be considered as $Co_{0.5}Pt_{0.5}$ alloy formation. This alloy is chemically disordered because peaks of ordered alloy $L1_0$, $L1_2$ and etc. are not detected. High resolution transmission electron microscopy (HR-TEM) images of cross-section of irradiated trilayer reveal mixing Co/Pt (lack of mass contrast between Co and Pt layers) but atomic layer structure is still posses. So in such way created oriented cobalt platelets can induce PMA in similar way as it was observed in [6].

Summarizing, the increase of irradiation energy firstly lead to formation of Co-Pt alloy without lattice destruction. Such alloy has PMA due to the presence cobalt platelets which conserve initial orientation. With an increase of incident power above 75 mJ/cm^2 the Pt/Co/Pt trilayer begins to melt and after recrystallization it loses initial crystal lattice structure which is observed as rotation of magnetic anisotropy to in-plane state.

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