Coupling of optical, magnetic, and electric effects in permalloy and gold-permalloy bilayer structures

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ABSTRACT

Significant photovoltages are induced by laser pulses in permalloy and permalloy-gold structures. The electric effects are maximized at the surface plasmon polariton conditions and depend on magnetic field with characteristic hysteresis. Both magneto-dependent and magnetically independent responses can be tuned with the structure geometry and composition.

Keywords: Plasmonics, photovoltage, plasmon drag effect, permalloy, gold-permalloy bilayer, magnetization

1. INTRODUCTION

Structures with combination of plasmonic and magnetic properties present interest for various applications in tunable plasmonics, nanomagnetics, spintronics and optically controlled magnetic memory [1, 2]. In hybrid magnetic-nonmagnetic structures, transient photocurrents induced by femtosecond laser pulses depend on magnetic field [2-4]. The coupling of electric, magnetic and plasmonic effects has been also recently reported in permalloy gratings [5]. Photovoltages generated by nanosecond laser pulses maximized at the plasmon resonance conditions where they depend on magnetic field with a characteristic hysteresis [5].

The goal of the current work is to further explore this interesting coupling of electric, magnetic and optical effects in structures of different geometry and composition, including pure permalloy structures and gold-permalloy bilayers. The effects observed in pure permalloy structures are presented in detail in [6]. Here we discuss them briefly and concentrate more on the effects observed in bilayers.

2. EXPERIMENTAL

In the experiment, we used flat and 1-D profile-modulated structures. The profile schematics of the samples are shown in Fig. 1(a). As flat substrates we use glass slides. Polycarbonate 1 D- profile modulated substrates are obtained from disassembled commercial DVD discs following Ref [7]. The permalloy and gold films with the thickness ~ 35 nm are deposited with thermal deposition onto the substrates. The profile-modulated structures have the modulation period of 740 nm, and the modulation height of ~ 70 nm for the pure permalloy Py/DVD structures and ~ 50-60 nm for the bilayer Au/Py/DVD structure.

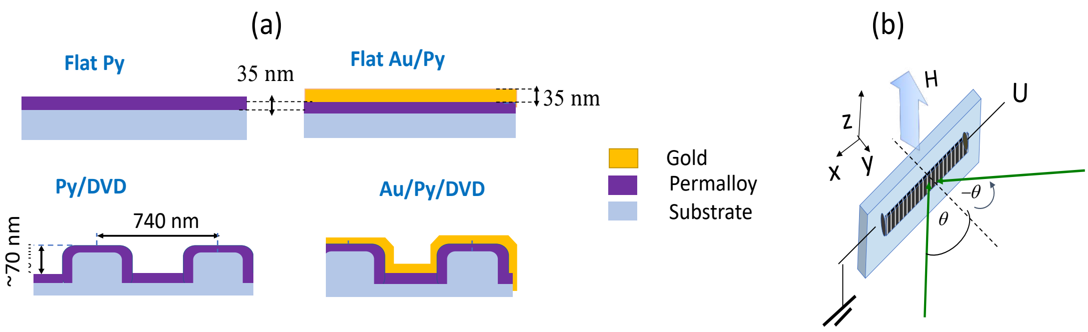

Figure 1.(a) Schematics of structures. (b) Geometry of the experiment.

In comparison with flat films, plasmonic and magnetic properties of the profile-modulated surfaces are affected by the modulation. Magnetically, the permalloy gratings have uniaxial magnetic anisotropy with the easy axis along the grooves and the anisotropy fields of ~ 80 Oe [8]. While no surface plasmon polariton can be excited in flat films by direct illumination, in profile-modulated films it can be excited at the matching conditions

$$k_{spp} = k_x + mG, \qquad (1)$$

where k_x is the projection of optical k-vector onto the grating plane, m is an integer, $G = 2\pi/T$, and T is the period of the structure. The estimation for our experimental conditions predicts the resonance incidence angle of ~20 deg.

The experimental samples are cut in the shape of a strip with sizes 3 mm x 15 nm. The orientation of the groves is perpendicular to the long side of the strip (see Fig. 1 (b). Two electrodes are placed on the opposite ends of the strip. The sample is placed on the goniometer stage inside the electromagnet with optical access. The sample is illuminated in the middle by the pulsed laser light at the wavelength of 532 nm, pulse duration ~ 5 ns, p-polarization, pulse energy of 0.1-0.3 mJ. The induced voltage is recorded by Tektronix oscilloscope.

3. RESULTS

Typical experimental kinetics recorded at two different magnetic fields in flat and profile modulated systems are shown in Fig. 2 (a, b). As one can see, in flat films, the signals at positive (upward) and negative (downward) fields are almost of the same magnitude but the opposite polarity. This is not the case in the gratings, where the signals at both positive and negative fields are of the same polarity and different magnitude. The difference between signals at downward and upward fields, U_{down} - U_{up} is positive in all cases and directions of light illumination.

The behavior of the signals at sweeping magnetic fields is shown in Fig. 2 (c, d). The magnitude of the signal shows a hysteresis. In the flat films, the hysteresis is narrow, with the polarity switching at the fields of a few Oersted. The size and the shape of the loop practically does not depend on the angle of incidence, being almost the same for positive angles, negative angles and normal incidence. Much broader hysteresis is observed in the profile-modulated structures. In this case, the position of the loop depends on the angle of incidence. When the incidence angle is negative (-20 deg), the loop lies in the positive half of the graph; at the positive incidence angle of 20 deg, it switches to the negative voltages.

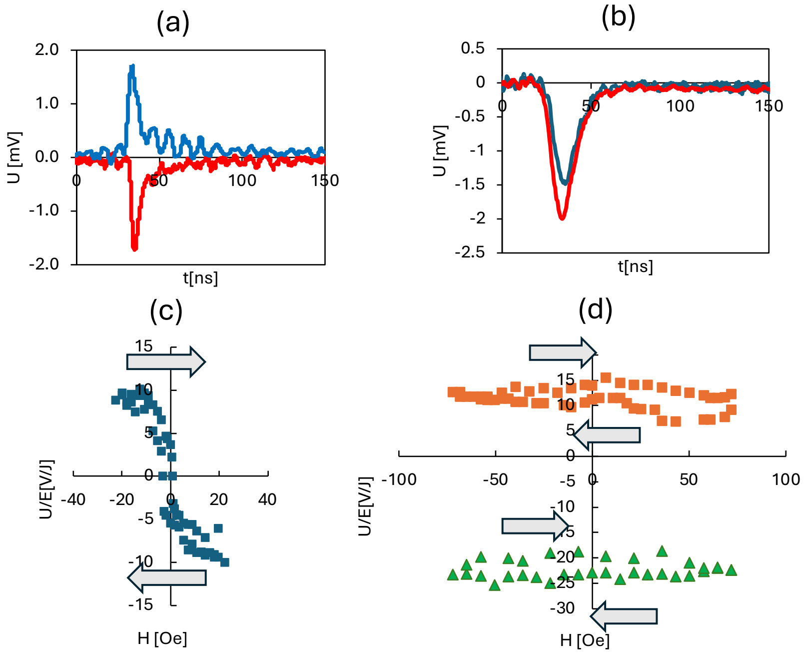

Figure 2. (a,b) Typical signals in (a) flat bilayer and (b) profile-modulated structure at the magnetic field of 90 G directed upward (red) or down (blue). (c, d) Magnitude of the voltage at sweeping magnetic field in (c) Flat Au/Py and (d) Au/Py/DVD at 20 deg (triangles) and -20 deg (squares). The signals in (c,d) are normalized to the pulse energy, *E*. The arrows show the direction of the field sweep.

These observations can be understood, assuming that there are two different contributions to the observed signal,

$$U = U_0 + U_M . \qquad (2)$$

U_0 is the plasmon drag voltage [9,10]. It does not depend on magnetic field and exists only at SPP resonance conditions. Electrons are dragged in the direction of SPP propagation. In the Au/Py/DVD geometry, the illumination at the incidence angles of 20 deg and –20 deg excites the plasmons in the opposite directions, resulting in the positive or negative values of U_0. This signal does not exist in the flat films since no plasmons are expected to be excited with the direct illumination from air. The second contribution U_M is evidently related to the magnetization. It contributes to the total signal with the different polarity depending on the magnetization of the sample and follows magnetization behavior at sweeping magnetic field. The width of the loop corresponds to the magnetic coercivity of the structure. The magnetization switches in the opposite direction at low fields in the flat structures. Higher fields are required to switch magnetization in the profile-modulated structures due to magnetic anisotropy related to the profile modulation [8]. Comparing gold permalloy structures with pure permalloy structures [6], the angular and magnetic dependence are very similar, but magnitudes of the signals are generally higher in pure permalloy.

Both contributions linearly depend on the light intensity at the fields outside the switching range. However, in the switching range, the dependence is nonlinear. This can indicate some light-induced changes in magnetization resulted from the exposure to strong laser light. In the experiment shown in Figure 3, the incident intensity changes from low values to high and then back to low intensity (using neutral density filters). The dependence is nonlinear and has a hysteresis: the signals at low pulse energies are different before and after the exposure to strong light.

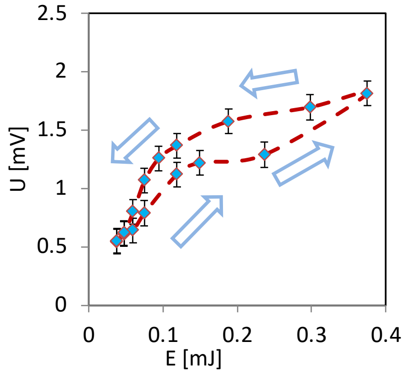

Figure 3. Photovoltage in Flat Au/Pt as the function of pulse energy. The arrows show the direction of the field sweep.

In conclusion, we have studied the photovoltages in flat and profile-modulated permalloy and gold permalloy films. The electric responses to pulsed laser light are determined by plasmonic and magnetic properties of the structures   The observed coupling of optical, magnetic and electric effects can provide opportunity to detect or monitor both plasmonic and magnetic excitations, this can present interest for various applications in plasmonics and nanomagnetics.

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