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SURFACE PLASMON RESONANCE IN As_2Se_3 PLANAR WAVEGUIDES FOR THE IR SPECTRAL REGION

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The surface plasmon resonance (SPR) four layers configuration that contains prism of BK7-gold metal film-As2Se3 waveguide-air was realized. As_2Se_3 thin films with low roughness were obtained by thermal evaporation using cvasi-closed evaporator. The surface roughness's was less than 2.5 nm. The SPR curves shape calculated by MATLAB solver were identical to these one calculated by matrix method. The As_2Se_3 films were characterized by ellipsometric spectroscopy and the obtained optical constants were used for calculations. Experimentally obtained SPR curves at the 1064 nm wavelength shown sharp resonance and are in accordance with calculus.

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1. Introduction

The solid amorphous materials have some specific optical properties who cannot be found in the crystalline state. One of the main phenomenon is photo-induced modification of optical constants (n, k), which can be used in various optoelectronic devices [1-4]. Unfortunately, the changes, though largely dependent on the material, are not very large [5-9]. This fact limits in many cases possible applications. Sometime morphological changes pointed out [10-13], memory phenomenon [14] or planar waveguides [15]. An efficient solution to the problem consists in achieving a resonance structure, when small changes in optical constants lead to a considerable change in transmission or optical reflection.

Such a structure would be the surface plasmon resonance, usually realized in Kretschmann configuration [16]. This consists in the use of a prism that ensures coupling with the surface plasmon-polariton wave through the evanescent wave, which is formed when the incidence uncle exceeds the value of the total reflection angle. The Kretschmann configuration requires that the coupling prism refractive index must be greater than that of the film deposited over the gold layer. In the case of chalcogenide materials, the refractive index ranges from 2.5 (for As_2S_3) to 3.0 (for As_2Se_3) and does not normally allow excitement of surface plasmon-polaritons with a prism made of conventional optical glasses such as crown, flint etc. The situation can be overcome if the film thickness is strictly selected so that surface plasmon-polariton wave resonates with one of the waveguide modes. Some experimental studies were perform and published by using arsenic sulphide films [17-18]. Although As_2Se_3 is a high band gap material and permits the operation in visible light, it is not the most appropriate material with considerable photo-induced changes.

The purpose of this research was to make calculations for SPR in structures that contain As_2Se_3 films in order to obtain the resonance curves. The thin films technology and spectroscopic ellipsometry data for optical constants serve for experimental studies.

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2. Preparation of As_2Se_3 Thin films

The most important requirement for obtaining films from amorphous chalcogenide glasses (ChG) is the reproducibility of the composition of the raw material, the homogeneity of the layer deposited in the composition, structure and roughness. The best known is the technology for depositing thin films in vacuum, which can be achieved by various methods: thermal evaporation in vacuum, cathode spraying, electron beam evaporation, instantaneous (explosive) evaporation, etc. For the amorphous glass semiconductors the first three methods are used. Based on simplicity and low cost, the method of thermal evaporation in vacuum was preferred. Depending on the composition and the condensation conditions of the vapors, when the bulk is transformed into film, crystalline, glass films with ultrafine or amorphous dispersion can be formed. In order to obtain a good adhesion of the layer deposited on the substrate, the latter before being deposited was treated at 100 ° C for 30 minutes.

One of the problems is finding such a vaporizer that the surface of the substrate is exposed equally. In general, the influence of the angles of incidence of the molecular fluxes, which lead to an inhomogeneous thickness of the condensate, can be reduced by increasing the distance from the evaporator to the substrate, by creating vaporizers at different angles of inclination or by using different evaporators as construction and positioning. in a way, one to the other. In this work, it was decided to modify the evaporator itself.

In order to obtain high quality stoichiometric ChG films, a special evaporator was designed and verified, the construction of which is close to a "quasi-closed" volume evaporator. For this purpose, the vacuum station VUP-4 was equipped with a temperature recording evaporator, the shape of the evaporator being modified to allow the creation of a constant and adjustable atomic flow with the exit of the evaporated gas under different inclinations to the substrate. Another autotransformer with an ammeter included in it was added to the vaporizer's power supply system. This made it possible to control the power of the power supply, necessary to ensure the temperature regime of the vaporizer. The construction of the vaporizer is provided with a specially drilled lid to ensure a uniform flow on the substrate so that a uniform film thickness could be obtained on a surface of 200 cm^2. In addition, on the side of it are fixed screens, the slope that ensures a uniform flow of steam on the substrate and, respectively, a uniform thickness of the film.

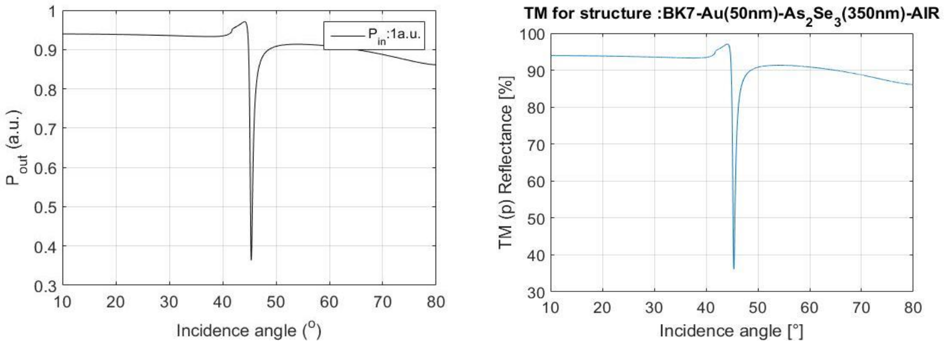
Precautionary measures have been established to obtain films with low roughness so as not to cause the resonance peak to widen. The surface roughness characterized by the atomic force microscope was 2.2-2.5 nm. The thickness of the As_2Se_3 film obtained by profilometric characterizations varied between 840-860 nm on a surface of 110x10 mm. When fabricating thin films of ChG, it was intended that the evaporation temperature of As_2Se_3 materials be at the beginning of evaporation as in case [19], which ensured that a constant condensation rate was maintained over a long evaporation time. The thickness of the deposited layer was determined by the evaporation time and, within certain limits, was adjusted by the diaphragms mounted above the evaporator.

The uniform distribution of the condensation thickness throughout the film was also ensured by the variation of the distance between the substrate and the evaporator. The distance between the evaporator and the substrate was greater than 21 cm. Evaporators used experimentally were from tantalum. At the vacuum deposition unit of type VUP-4, As_2Se_3 vacuum films of $3.0x10^{-5}$ Torr were obtained. Thus, using the newly developed vaporizer for thermal deposition in vacuum, it was possible to obtain films of stoichiometric composition, small roughness and with a uniform thickness.

3. SPR numerical calculations

Helmholtz equation has analytical solution only for a metal-dielectric interface. Or, in the Krechsman configuration there are at least two interfaces (prism-metal and metal-air). To find out the solution, a transcendental equation is reached. Its solution allows obtaining the resonance curve expressed by the dependence of the reflectance depending on the angle of incidence R (Θ), but also the distribution of the electromagnetic field in the direction perpendicular to the layers.

In sensor applications, it is necessary to obtain only the shape of the resonance curve and its sensitivity to the variation of the refractive indices. In this, the matrix formalism was applied widely. A general method would be to solve a linear system of equations for which there is solver in MATLAB. The benefit would be that in this case the field distribution could also be obtained.



(a) *(b)*

Fig. 1. The shape of SPR curves obtained by two methods of calculation:
(a) METLAB solver for sistem of linear equations and (b) Matrix method.

For the approval of the method, the reflectance of the laser radiation was calculated by both methods (matrix and MATLAB solver). The results for the following structure are presented below for 4-layer arangement: BK7 (n = 1.5007), Au (50 nm, n = 0.5748-9.6643i), As_2Se_3 (350 nm, n = 2.8) and air. The selected wavelength is 1550 nm. The results are shown in Figure 1. According to both figures, the minimum of reflectivity is obtained for the angle of incidence of 45.37 degrees, and the total variation of the reflectivity is from 80% to 35% over a range of variation of the angle of 1.2 degrees. The results are in good agreement, which means that I can use the software based on the solver from the MATLAB library, which can also calculate the distribution of the electromagnetic field in the 4 regions of the plasmonic guide.

The results for the following steps of the study will be presented below: the guide structure analyzed as thickness, absorption, refractive index, but also the wavelength of the probe laser. In order to design the experiment, the dependencies of the light reflectance on the structure with plasmonic resonance were studied analytically depending on various factors and finding the optimal conditions. The structure examined is the following: Prism from BK7, Au metal film with different thicknesses, amorphous As_2Se_3 film with different thicknesses. Calculated configuration: TM modes and 1064 nm wavelength. The extinction coefficient and the refractive index were taken from the ellipsometric characterizations of the As_2Se_3 films presented in the following section. The parameters are following (Fig. 2): TM modes at $\lambda = 1064$ nm. Refractive index n=2.78, extinction coefficient k=0.01. Configuration is 4-layers: Prism-gold film-As_2Se_3 film-air.

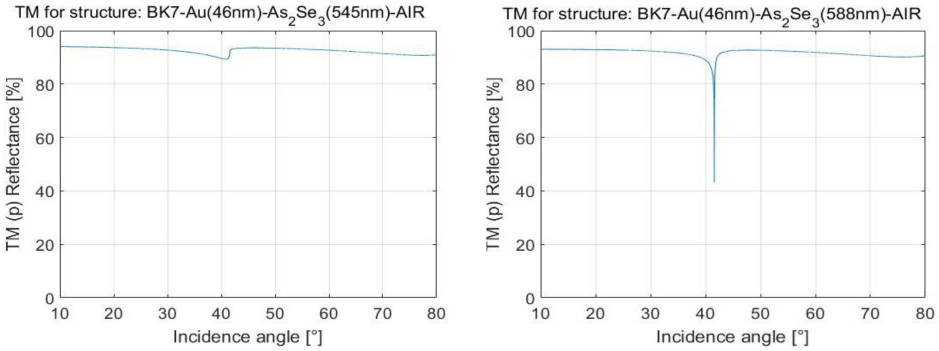
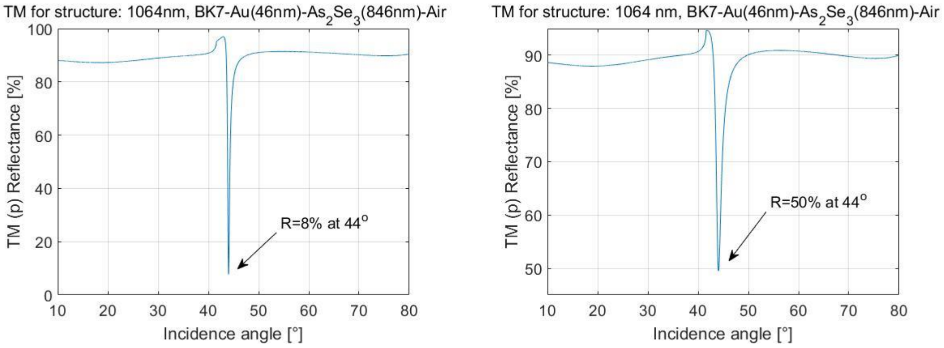


Fig. 2. SPR resonance curve for gold film of 46 nm and two thicknesses of As_2Se_3 (545 nm and 588 nm).

Conclusions: For the thickness of 588 nm a narrow resonance curve is obtained, well for spills. However, the minimum does not fall below 30-40%. This does not happen due to absorption. The extinction coefficient k = 0.01 corresponds to an absorption coefficient α = 100 cm-1 which is not much but it has been shown to significantly influence the minimum reflection value. In figure 3 are presented the calculations for an As_2Se_3 film that does not absorb (k = 0) and with absorbance k = 0.01. From the graph, it is observed that even a poor absorption decreases the quality of the structure with SPR and leads to an increase of the reflectance in mins up to 50%. For films without reflective absorption at a minimum, it drops to 8% that can be even smaller by optimizing the film thickness.



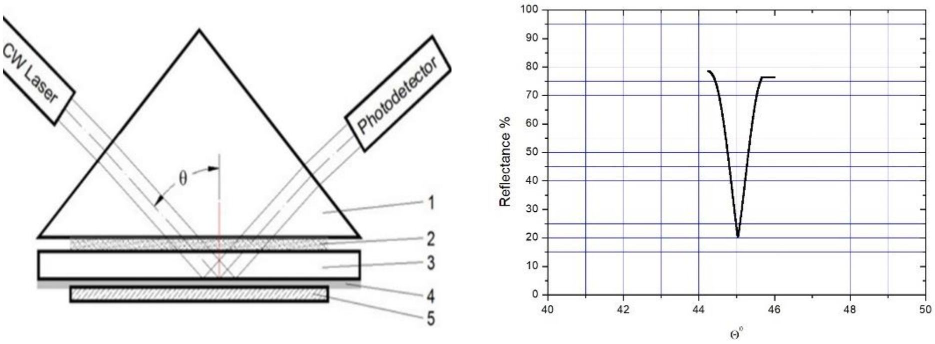
(a) *(b)*

Fig. 3. Resonance curve of the plasmonic structure for k=0 (a) and k=0.01 (b) As_2Se_3 layer thickness is 846 nm and Au film thickness is 46 nm in both cases.

4. SPR setup and experimental results

The experimental setup for studying the SPR reflectivity from structure presented in Fig. 4. The plasmonic structure contains a chipset made up of a glass slide with a thin gold film. We used a standard chipset from XanTec bio-analytics. The film consists of bare gold film with thickness of 46 nm measured by profilometer. The refractive index considered from [20] was n = 0.6827- i2.0203 for the laser wavelength of 1064 nm.

The amorphous chalcogenide As_2Se_3 film has the refractive index of 2.78 for the wavelength 1064 nm and was determined by spectroscopic ellipsometry. It has deposited on top of the gold film by thermal evaporation in conditions described before. The clean, uncovered face of the chipset is attached to the base of a 45°x45°x90° prism by using Cargille microscope immersion oil of type A which has the refractive index n = 1.51.



(a) (b)

Fig. 4. Experimental setup (a) for the investigation of SPR with nonlinear film: 1-prism of BK7 glass; 2-immersion oil; 3-substrate glass slide; 4-gold film; 5-As_2Se_3 amorphous film. b) Experimentally measured SPR in configuration with As_2Se_3 amorphous film.

The prism made by BK7 glass (*n* = 1.505) was mounted on a Thorlabs NR360S continuous nano-rotation stage, with the rotation axe perpendicular to the plan of the figure. The one arcsec resolution of the rotation stage ensures the measurement of the plasmon resonance angle with the high accuracy. The irradiation of linearly polarized laser beam was incident on the base of prism The beam polarization is the plane of incidence so that TM modes can be excited. The laser was a diode which is CW and generates up to 15 mW power. The reflected radiation was measured by a digital power-meter (Gentec Solo PE). Every measurement of laser power was synchronized with rotation of table.

5. Discussions

The structures with surface plasmonic resonance are of interest for applications due to the high sensitivity to small changes of the refractive index, of the order 10^{-5}-10^{-6}. The interaction of light with the plasmon-polariton wave occurs at dimensions below the wavelength, so it is the nanoscience domain. To optimize the sensitivity, structures that are more complex are needed. The use of amorphous chalcogenide films such as As_2Se_3 are interesting for two reasons: First, the high index of the refraction coefficient leads to a better confinement of the field and the possibility of making planar waveguides. Second, the enhancement of reflectance changes due to photo-induced modification of optical constants when films are placed in a resonance structure such as SPR. That leads to considerable changes in the light intensity even if the variation of the optical parameter is insignificant. The calculations indicated that the optical constants of this material are suitable for achieving multilayer structures of plasmonic resonance, when the film acts as a waveguide. Experimental results on structures containing amorphous As_2Se_3 films have shown that this material exhibits a very narrow resonance curve, below 1^o in the IR domain.

6. Conclusions

As_2Se_3 films allow us to obtain a narrow plasma resonance curve. This indicates that the films are promising for various photonic applications. Because a prism is used for the coupling of light, it is important that the prism is made of a cheap and well-approved material such as, for example, the BK7 type glass. As was established this can be achieved, but the thickness of the film must be at certain thickness intervals. Plasmonic resonance is achieved only with one of the modes of the planar waveguide. The surface of the film must be very smooth, with low roughness, so that the experimental resonance curve corresponds to that obtained from numerical simulations. The technology used must ensure such surface quality. In case of thermal evaporation in vacuum, it is necessary to use a closed type evaporator to avoid droplets and clusters of considerable size.

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