A thorough study of terahertz surface waves travelling along metal-dielectric surfaces of different curvature and jumping through air gaps

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***Abstract*—Experiments on study of surface waves launched with a monochromatic terahertz source are described. We compare characteristics of the surface waves at the gold samples of different curvature covered with thin dielectric layers. Transmission of SEWs across surface impedance boundaries and air gaps is also examined.**

I. INTRODUCTION

SURFACE electromagnetic waves (SEW), also referred to as surface plasmon polaritons (SPP), attract a special interest in material study, photonic devices, diagnostic systems, and other applications [1, 2]. Up to now, there is no complete understanding of these waves in the terahertz spectral range, because of disagreement in some aspects between theory and experimental data for the waves on plane surfaces [3] and the absence of a reliable theory for SEWs on curved surfaces. In this paper we present the results of comprehensive experimental study of SEWs generation, transmission along plane and cylindrical gold surfaces covered with ZnS layers of different thickness, as well as jumps of the surface waves across air gaps. Theories describing the waves on cylindrical surfaces are compared with the experiments.

II. RESULTS AND DISCUSSION

Main experimental configurations are shown in Fig. 1. Some of the experiments have been performed using modifications of these setups. As a source of monochromatic terahertz radiation, we used the Novosibirsk free electron laser [4]. All experiments have been carried out using the wavelengths from 120 to 140 µm with relative line width of about 1%. Surface waves were launched by end-fire coupling technique [5]. To divide coupled SPP and the balk wave we used a cylindrical surface (Fig. 1, a). Though the theories did not confirm existence of THz SPP for our parameters, we observed the waves ("creeping waves" [6] or SPP?) travelling along the cylindrical surfaces via measuring radiation scattered in the tangent direction for all eight cylinders with ZnS layer from 0 to 2 µm.

The results are presented in Fig. 2. The propagation length was small for thin dielectric layers, grew up to maximum value for the layers of 1.0 and 1.5 µm thick, and rapidly felt down when the thickness became 2 or 3 µm (see Fig. 3). In further experiments (Fig. 1, b, c) we permanently used the cylinder with ZnS layer of 1.5 µm to form an SPP and transmit it to a plane sample or air gap. The dependence observed can be explained by existing of two losses mechanisms: the ohmic losses growing with the ZnS thickness and the radiation losses, which, in turn, may have two causes, surface curvature and surface non-uniformities. Results of our experiments have shown that surface plasmon polaritons at a frequency of about 2.3 THz obviously exist on gold-dielectric-air cylindrical surfaces with a curvature radius of 60 mm, though preliminary calculations based on Drude model denied that for tabulated material parameters.

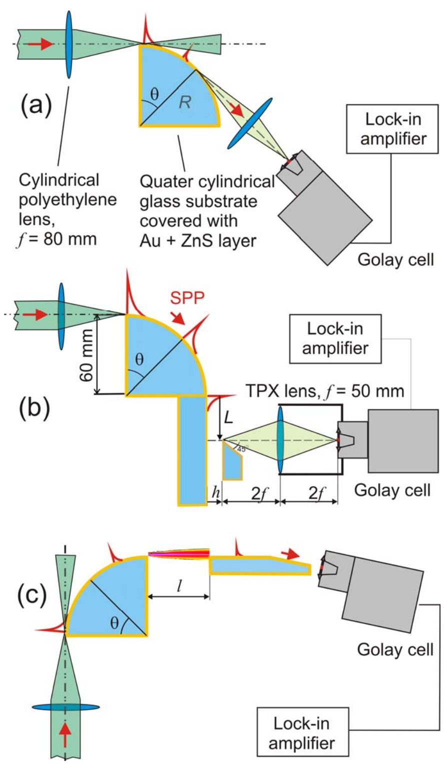

Fig. 1. Experimental setups: (a) Study of surface waves moving along cylindrical surfaces via sensing scattered radiation intensity vs. θ; (b) Study of propagation length L and intensity distribution normally to surface h for the waves travelling along plane surfaces; (c) Study of SPP jumps through air gaps.

Attaching plane samples directly to the quarter cylinder end (Fig. 1, b), we studied the waves travelling along the surface as a function of length L (propagation length) and distance from the surface h (decay length). In these experiments we used the technique described in detail in Ref. [1]. We observed a strong dependence of the results from the ZnS layer thickness. We observed two-peak shape for the wave decay. The peak close to the surface we considered to be SPP, whereas the next one may be treated as radiation losses or as creeping waves. Propagation lengths for these two peaks were different and depended on the ZnS layer thickness.

Experimentally measured characteristics of SPP travelling along plane surfaces evidence that the SPP decay length is in a good agreement with the Drude model, whereas the propagation length is much less than theoretically calculated.

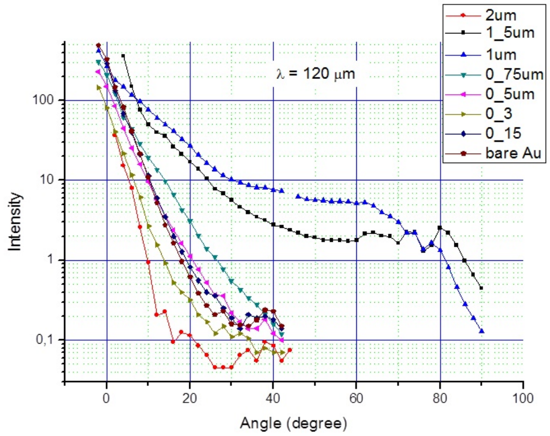

Fig. 2. Intensity of radiation measured with the Golay cell in the configuration shown in Fig. 1, a for cylinders with different ZnS layer thickness.

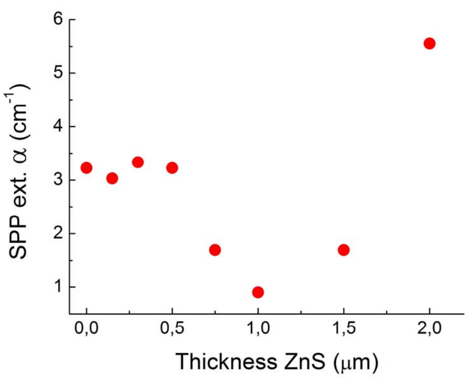

Fig. 3. Extinction coefficient for the surface wave travelling along cylindrical surface.

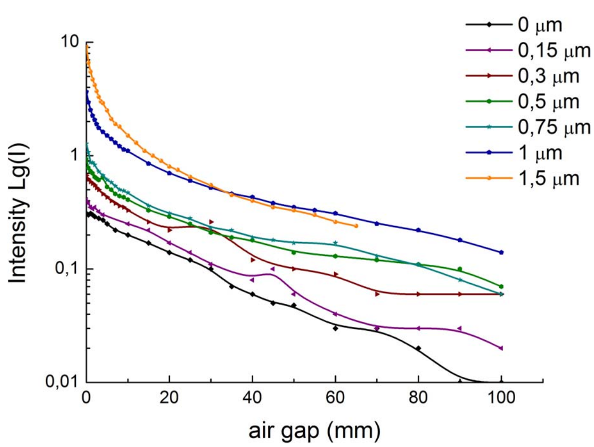

Fig. 4. Surface plasmon "jumps": intensity of radiation measured with the Golay cell in the configuration shown in Fig. 1, c for the target samples with different ZnS layer thickness.

Attaching to the transmitting cylinder an additional short plane sample with a slope at the end and increasing distance between them (Fig. 1, c), we have studied SPP jumps through air-gaps of different length. For an optimal sample combination, efficiency for SPP re-coupling even for l = 100 mm was not less than 1%. Intensities of surface plasmons recoupled to the end of the receiving samples with different ZnS layer thicknesses and detected with the Golay cell are shown in Fig. 4. Jumps of SPP through so long air gaps can be employed for development of optoelectronic systems.

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