Surface plasmon propagation along plane metal-dielectric interfaces with air gaps

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***Abstract*—Propagation of terahertz surface plasmon polaritons along plane metal-dielectric interfaces and their jumps across air gaps have been studied using monochromatic radiation of Novosibirsk free electron laser.**

I. INTRODUCTION

GUIDING systems for integrated circuits (ICs) are key elements in the development of compact photonic instrumentation[1]. Terahertz (THz) radiation can be transmitted both inside an IC module and between electrically isolated modules by means of "jumps" of SPPs across air gaps. To select optimum characteristics of SPP guiding systems one has study the following three physical phenomena: propagation of SPPs along metal-dielectric interfaces, SPP scattering, and SPP jumping.

Until now, propagation and scattering of SPPs in the THz range, with few exceptions, were studied for some interfaces by the TDS technique[2]. In this paper we have examined these phenomena using tunable monochromatic terahertz radiation of Novosibirsk free electron laser[3,4], which operated in the experiments described at the wavelengths of 130 or 140 µm. An analytical expression for SPP diffraction on a conductive surface edge, which describes the decoupled wave in both the near- and far-field zones, has been first derived[5] and verified experimentally[6].

II. EXPERIMENT

Using an open parallel-plate waveguide, we launched surface plasmons along a gold-ZnS-air interface 17 cm long, the ZnS thickness varying from zero to 3 µm. Upon reaching the surface edge, the SPPs diffracted into the free space (see Fig. 1, where either a 320x240 microbolometer focal plane array[7] or a Golay cell were applied for detection of the decoupled electromagnetic field (EMF).

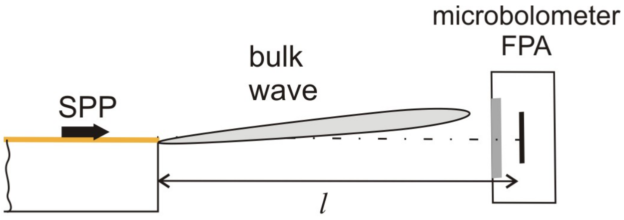

Fig. 1. Imaging detection system with a microbolometer focal plane array

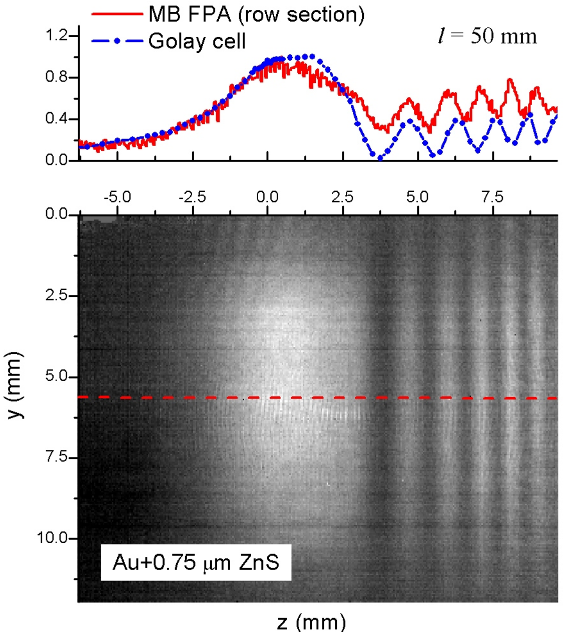

Fig. 2. Intensity distributions of the diffracted wave at $l = 50$ mm beyond the edge obtained with the Golay cell (blue dots in the plot) and with the microbolometer FPA (the frame below and red curve on the plot)

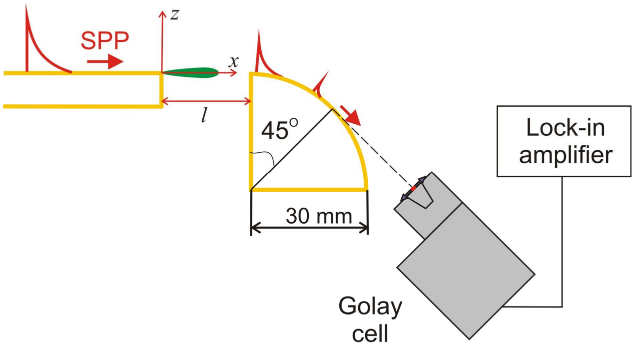

Fig. 3 The experimental scheme of SPP transmission through the air gap

Examples of an image obtained with the MBFPA and a trace recorded with the Golay cell are shown in Fig. 2. Using these non-invasive techniques, we have studied the SPP propagation length (PL) and decay length (DL) depending on ZnS layer thickness, characteristics of the decoupled waves, and jumps of SPPs between two samples against the gap length. The latter was studied using the experimental configuration shown in Fig. 3. The diffracted radiation was recaptured by a quarter-cylindrical sample, which surface also was covered with a gold-ZnS layer.

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III. RESULTS

The SPP propagation length and decay length drastically depended on the ZnS thickness. Experimentally measured decay lengths for all interfaces were in good agreement with the Drude theory (few millimeters), whereas the propagation lengths (a few centimeters) was about three orders less than the theoretical one. This contradiction is well-known and still requires thorough investigation.

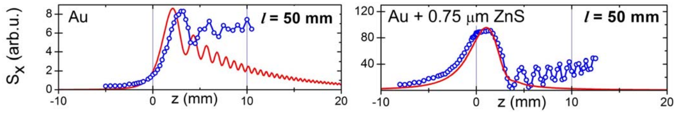

Fig. 4. The distributions of the EMF energy flow beyond the edge: theory (red curve) and experiment(blue poins)

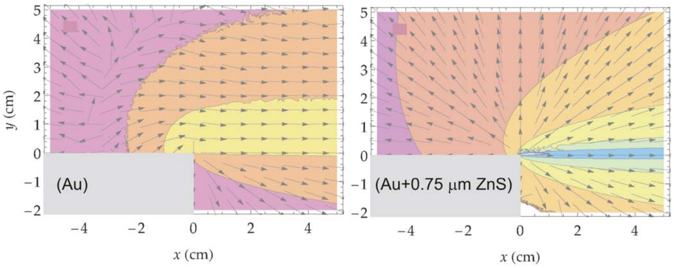

Fig. 5. The Poynting vector magnitude (intensity levels are given in the logarithmic scale) in the vicinity of the sample end (theory)

The experimental and theoretical distributions of the longitudinal EMF energy flow $S_x(z)$ at the distance $x = 50$ mm beyond the edge (Fig. 4) were found to be in reasonable agreement. It was found that deposition of a very thin (~ $10^{-3}\lambda$) dielectric layer substantially decreased the intensity distribution width of the diffracted wave. This effect is clearly demonstrated by theoretical calculations of the Poynting vector in the vicinity of the edge. In Fig. 5, the Poynting vector direction is shown with arrows, whereas its magnitude in the logarithmic scale is shown with color gradation.

If to place second sample beyond the first sample end, a portion of the diffracted wave is recaptured and converted again in SPP travelling along the sample surface. We observed such plasmons on the rectangular samples, but possible interference between SPP and the idle bulk wave did not enable to obtain reliable results. To overcome the problem, we applied as the second sample quarter cylinders with the curvature radius of 30 mm. SPP propagation length along cylindrical surface measured in special experiments was equal to 17 mm and 12 mm for 0.5 and 1 μm ZnS layer, respectively. Efficiency of SPP recapture was detected by measurement of the radiation emerging because of SPP radiation loss at the angle 45° (Fig. 3), where the interference with the bulk wave is impossible. Radiation intensity as a function of the gap length measured for two cylinders with different thickness of ZnS layer is shown in Fig. 6.

Rather high efficiency of SPP jumping across the air gaps can be explained by the high directionality of the diffracted wave (see Fig. 5). To measure

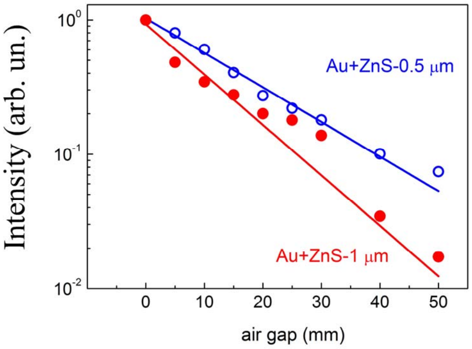

Fig. 6. The transmission of SPP vs. air gap

IV. CONCLUSION

Our multivariate analysis of SPP propagation, diffraction and jumping, both experimentally and theoretically, clearly indicates technical feasibility of application of surface plasmon polaritons on metal-dielectric-layer interface for the development of guiding systems in the THz integrated circuits and other 2D THz devices. The narrow angular distribution of the diffracted waves is also favorable for development of THz radars.

ACKNOWLEDGMENTS

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