Metasurface pathways for surface guiding of confined terahertz spoof surface plasmon polaritons on routes with subwavelength width

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Abstract—We report the realization of ultrathin metallic metasurface pathways that can guide strongly confined spoof surface plasmon polaritons (SSPP’s) at terahertz frequencies. The subwavelength metasurface path width enables a tight in-plane confinement of the SSPPs, which allows to route them along arbitrary signal paths without the loss of their field confinement perpendicular to the surface. By the use of a near-field imaging terahertz spectroscope, we were able to investigate propagating SSPP’s on fabricated samples, which delivers new insights into the spatio-temporal and spectral properties of these guiding structures.

I. INTRODUCTION

The realization of high speed photonic networks with high integration rates requires new technologies that provide the ability of downsizing processing components and combining various applications into a single chip. A promising approach to accomplish this task is provided by the concept of a spoof surface plasmon polariton (SSPP), that is a surface wave mode on specifically designed guiding structures. The beneficial properties of SSPPs are the subwavelength field confinement and the ability of breaking the diffraction limit, which is essential for implementing signal paths in highly integrated photonic circuits. To enable SSPP modes at microwave or terahertz (THz) frequencies, these signal pathways have to be composed by metasurfaces with tailored dispersion characteristics. Appropriate types of metasurfaces are ultrathin metallic metamaterial structures, that can be directly integrated into printed circuit boards. Recent publications about investigations of terahertz SSPPs on metasurfaces, lack experimental evaluation. The literature is either restricted to numerical simulation models [1] or refers to proof-of-principle experiments in the microwave regime [2]. In contrast to that, we implemented ultrathin metallic metasurface pathways that support terahertz SSPPs and experimentally verified the propagation of terahertz SSPP modes on fabricated samples. The proposed metasurface is composed by periodically arranged metallic cut-wires, that are attached to a polymer thin film substrate via standard lithography (see Fig.1(a)). By limiting the number of cut-wires in the direction transverse to the propagation, we confined the path width, that defines the in-plane boundaries for the SSPPs, to subwavelength dimensions. Furthermore, we were able to arrange the cut-wires on curved pathways, which allows in-plane routing of propagating SSPPs in arbitrary path directions. To experimentally investigate the propagation of SSP modes on fabricated samples, we electro-optically mapped the near-field of the SSPPs by use of a 20 µm thick, X-cut lithium niobate (LN) crystal. By raster scan, we were able to extract the full information about amplitude and phase of the terahertz signal at each scan point.

II. RESULTS

Figure 1(b) shows the measured electric near-field of the SSPPs on a curved metasurface pathway at a frequency of 0.29 THz. By use of the amplitude and phase of the electric field, we were able to experimentally study the spatio-temporal and spectral dynamics of the propagation process, the in-plane and out-of-plane field confinement and the dispersion of the SSPPs on the given route. The investigation of specific temporal and spatial dispersion properties of the SSPPs was enabled by the implementation of a thin (20 µm) LN crystal as an electro-optical detector. By choosing the crystal thickness much smaller than the corresponding wavelengths in the terahertz observation spectrum, we avoid discrete etalon effects in the detector, which allows us to record long time traces of the terahertz pulses without capturing undesired signal parts. Since the dispersion of the metasurface massively spreads the temporal pulse width of the propagating SSPPs, the time trace of the SSPPs must be measured over relatively long time windows to collect the full information about the properties of the SSPPs. By use of the thin LN crystal, we were able to capture all necessary information about the SSPPs without picking up additional signal distortion.

Figure 2(a) shows an exemplary time signal of the measured electric near-field along the metasurface. As indicated by the green dashed frames, we observe two distinguishable signals in the time trace. In the left frame, we recognize residual
transmission of the incident terahertz pulse through the coupling edge that only partially couples the incident pulse into the propagating SSPP mode. In the right time frame however, we exclusively measure the near-field of the propagating SSPP along the pathway of the metasurface, as the SSPP propagation temporally occurs after the coupling process and therefore is distinct in the time domain.

This is also evidenced by the 2-D maps of the measured electric near-field along the metasurface in Figs 2(b) and 2(c). In Fig. 2(b), the electric near-field has been recorded during the left time frame in Fig. 2(a). Within this time window, the incident terahertz pulse partially participates in the excitation of the SSPP, while a significant fraction of the pulse is transmitted through the coupling edge and directly measured in the near-field map. After about 20 ps, the coupling process is completed and only the propagation of the SSPP along the metasurface pathway is measured, when the time trace is recorded during the right time frame in Fig. 2(a). As can be seen in Fig. 2(c), the strong confinement of the SSPP to the metasurface pathway becomes evident in this time period and is not overcast by the residual transmission of the incident terahertz pulse through the coupling edge. For achieving this strong in-plane confinement of the SSPPs, we reduced the metasurface path width in the direction transverse to the propagation direction. By design of the metasurface pathway, we were able to guide the SSPP along the devised route over a propagation length of several millimeters, while maintaining a subwavelength in-plane and out-of-plane confinement. Furthermore, we investigated the impact of downsizing the SSPP path width on the SSPP mode characteristics, which is important for the proper design of integrated terahertz photonic networks.

III. SUMMARY

We theoretically and experimentally evaluated the propagation of strongly confined SSPPs on metasurface pathways in the terahertz regime. We designed ultrathin metallic metasurfaces that can tightly guide these terahertz SSPPs along arbitrary signal routes. By applying electro-optical detection for mapping the electric SSPP near-field, we visualized the propagation of terahertz SSPPs and studied the spatio-temporal dynamics of the propagation process in detail.

REFERENCES