Integrated Spoof Surface Plasmon Devices and Circuits

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***Abstract* — In this presentation, I will review recent advances of spoof surface plasmons in the microwave, millimeter wave, and terahertz frequencies based on ultrathin metallic strictures. In details, I will introduce an ultrathin transmission line of spoof surface plasmon polaritons (SPPs) on corrugated metallic strip, which can be printed on ultrathin and flexible dielectric film to support conformal surface plasmons; an ultrathin corrugated metallic disk to support spoof localized surface plasmons (LSPs); passive SPP devices; active SPP devices for amplifying SPP signals and generating the second harmonics of SPPs; and the combined SPP and LSP circuits. Experimental results are presented for the SPP and LSP devices and circuits.**

I. INTRODUCTION

SURFACE plasmons (SPs) are highly localized surface waves existing on the interface of media with positive and negative permittivities, and hence are naturally supported in the optical regime. At lower frequencies (microwave, millimeter wave, and terahertz), SPs do not exist due to the lack of naturally negative permittivity. With the aid of plasmonic metamaterials, spoof SPs have been presented by making artificial structures on the metallic surfaces [1]. However, the structured metallic surfaces usually have three dimensions, which are difficult to be used in functional devices and integrated circuits in the microwave, millimeter wave, and terahertz frequencies. Here, we present the systematical work of spoof SPs on planar structures, which can be easily integrated in circuits and systems.

II. SPOOF SURFACE PLASMON POLARITONS

We firstly introduce a planar plasmonic metamaterial on ultrathin metal films with nearly zero thickness [2, 3]. From the theoretical simulations and experiments, we show that spoof surface plasmon polaritons (SPPs) can propagate along an ultrathin metal film by corrugating its edge with periodic array of grooves. Such a planar plasmonic metamaterial can sustain highly localized SPPs along two orthogonal directions in the terahertz and microwave regions in broadband by keeping good modal shape and propagating long distance with low bending loss. The ability to bend spoof SPPs freely on thin film makes the planar plasmonic metamaterial more practical to produce plasmonic devices in the terahertz and microwave frequencies, such as the bends, splitters, filters, polarizers, and resonators [3-10]. Experiments have been conducted to validate the feasibility of planar plasmonic metamaterial [2,3]. Based on the above idea, we present the concept of conformal surface plasmons (CSPs), i.e., the surface plasmon waves that can propagate on ultrathin and flexible films to long distances. The flexible ultrathin films can be bent, folded, and even twisted to mould the flow of CSPs. Fig. 1 demonstrates the simulation and experimental results of the CSP propagation on a spiral surface [2].

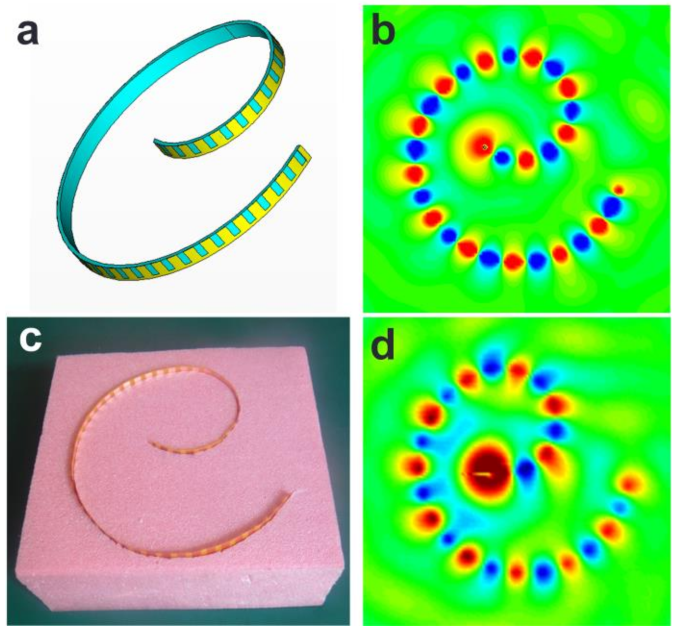

Fig. 1. The propagation of spiral CSPs on a complicated surface [2]. (a,c) The designed model and the fabricated sample with a 20-mm curvature radius in the beginning. The flexible and ultrathin CSP strip is supported by foam. (b,d) Full-wave simulation and experimental results of near-field distributions on the plane which is 1.5 mm above the spiral sample at 11 GHz. Excellent propagating performance of CSPs along the spiral surface is observed.

III. SPOOF LOCALIZED SURFACE PLASMONS

We further propose and experimentally demonstrate spoof localized surface plasmons (LSPs) on a planar textured metallic disk at the microwave and terahertz frequencies [11-13]. We design and realize the plasmonic metamaterial using ultrathin metal film printed on a thin dielectric substrate and observe the multipolar plasmonic resonances in both numerical simulations and experiments, including the dipole, quadrupole, hexapole, octopole, decapole, dodeca-pole, and quattuordec-pole modes [11], as illustrated in Fig. 2. The simulation and experiment results have very good agreements. We show that the spoof LSP resonances are very sensitive to the disk's geometry and local dielectric environments, and hence the ultrathin textured metallic disk has potential applications as plasmonic sensor in the microwave and terahertz frequencies. To reduce the LSP particle to the subwavelength scale, we proposed a spirally corrugated metallic disk, from which both electric and magnetic dipole resonances are observed [12]. More recently, we have extended the concepts of spoof LSPs to high orders [13], and obtained the second- and third-order LSPs on the ultrathin corrugated metallic disk.

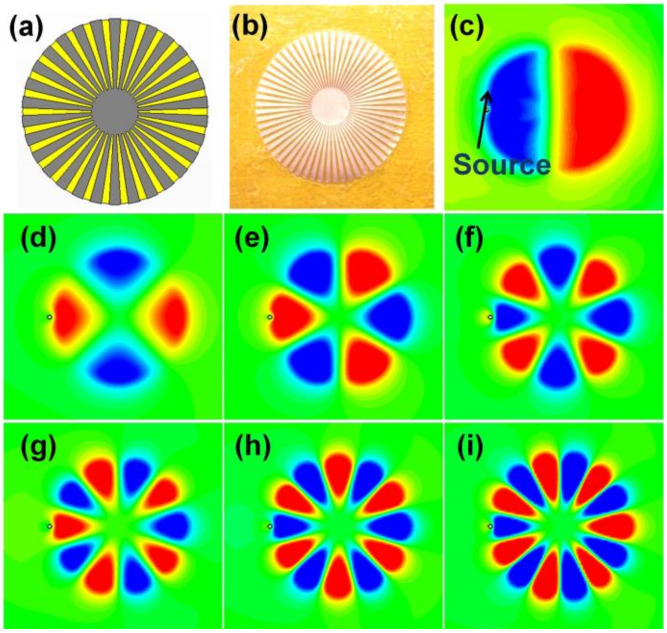

Fig. 2. (a, b) The planar textured metallic disk [11]. (c-i) The near-field patterns of vertical electric fields on a plane 0.5 mm above the textured metallic disk for the dipole mode (c), quadrupole mode (d), hexapole mode (e), octopole mode (f), decapole mode (g), dodeca-pole mode (h), and quattuordec-pole mode (i), respectively [11].

IV. Active Spoof SPP Components

In optical frequencies, active SPPs must be incorporated with bulky gain media. In microwave, millimeter wave, and terahertz frequencies, however, due to the great achievements of semi-conductor technologies, the active devices can be easily realized by active chips. Here, we present active spoof SPP devices using the subwavelength-scale amplifier chips, including the significant amplification of SPP waves [14] and higher-order harmonic generations of SPPs [15], which result in the SPP amplifier and SPP mixer. When the active chip works in the linear region, the experimental results show that spoof SPPs can be directly amplified by the amplifier chip from 6 to 20GHz with high gain around 20dB [14]. When the chip works in the nonlinear region, we experimentally demonstrate the efficient generation of second-harmonic SPPs in the broad frequency band [15]. The proposed method can be directly extended to achieve high-order harmonics of SPPs.

We also propose efficient conversion between conventional spatial waves and spoof SPP modes [4]. Recently, we presented a SPP and LSP combined circuit to control the SPP and LSP waves [16]. Based on the conversion and passive and active SPP and LSP devices, we propose integrated spoof passive/active SPP/LSP circuits to realize a series of functionalities and SPP systems.

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