Spoof Surface Plasmons and Applications in Microwave Frequencies

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Abstract: We present several spoof surface plasmon structures in the microwave and terahertz frequencies, including surface plasmon polariton (SPP) waveguides and the relevant devices, and localized surface plasmons (LSPs). In details, we will introduce our recent work on ultrathin and flexible SPP waveguides with subwavelength width, which can sustain highly localized SPPs along two orthogonal directions in broadband by keeping good modal shapes and propagating long distance with low bending loss, and the resulting compact plasmonic filters, bends, beam spillovers, polarizers, and resonators. We also demonstrate spoof LSPs on planar ultrathin textured metallic disks with subwavelength scales, which have potential applications as plasmonic sensors in the microwave and terahertz frequencies.

Keyword: Surface plasmon polaritons (SPPs), conformal surface plasmons, localized surface plasmons, SPP waveguide, passive SPP components, active SPP components.
References


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Outline

- Background and Motivations
- Conformal Spoof SPPs and Devices
- Conversion from SPPs to Guided Waves
- Spoof Localized SPs
- Conclusions
Spoof (or Mimicking, Designer) SPPs

- Natural SPPs only exist at optical frequencies.
- To realize SPPs at lower frequencies (GHz, THz), spoof SPPs have been proposed.
- The concept of “designer” surface modes opens opportunities to control and direct the radiations at surfaces within a subwavelength region.

A theoretical study on localized surface plasmons (LSPs)

F. J. Garcia-Vidal, PRL 108, 223905, 2012
The Motivation of Our Study

- The existing spoof SP structures are all 3D (corrugated structures on metal surface, drilling holes on metal surface, Domino structures).
- They are inconvenient for integration.

Our motivations:
- To propose, design, and realize spoof SPPs and LSPs on ultrathin metal surfaces;
- To construct planar and conformal SPP waveguides, SPP devices, and SPP circuits;
- To propose and construct ultrathin planar LSPs.
The proposed ultrathin SPP structure works from microwave to THz frequencies.
Spoof SPPs on Ultrathin Metal Film

- Experiment results: Wideband (7GHz – 11 GHz)
- Excellent propagation properties with low loss and long propagation distance.
- Low loss
- Good modal shape
- Long distance
- Exponential decay in both orthogonal directions
Spoof SPPs Devices

Shen and Cui, APL 102, 211909, 2013

Beam Bending  Beam Splitter
(Wideband)

Ring Resonator
Spoof SPPs Devices

Gao et al., APL 102, 151912, 2013

Dual-Band SPP Frequency Splitter
Flexible Copper Clad Laminate (FCCL)

Flexible and Conformal SPPs

Efficient Polarization Conversion

Sharp Bending
Flexible and Conformal SPPs

Conversion of Guided Modes and SPPs

Conversion of Guided Modes to SPPs

- Very high efficiency
- Very broad band
- Direct measurements of reflection & transmission
Advantage: Very Small Cross Talk
SPP Filters

Pan et al., Opt. Exp. 22, 13940 (2014)
SPP Filters
Spoof Integrated SPP Circuits

Shen, Zhang & Cui, unpublished, 2014

- Five-Port Circuit:
- Splitter
- Ring Resonator
- Directional Coupler
Radiation of SPP Waves

Xu et al., Efficient conversion of surface-plasmon-like modes to spatial radiated modes, APL, accepted for publication, 2015

A Spoof SPP Emitter, in which the gradient index metasurface will change the SPP modes to radiated modes.
Radiation of SPP Waves

Different gradience of the metasurface will result in different radiation performance.

\[
\frac{d\Phi}{dx} = 0.9 \, k_0, \, 1.353 \, k_0, \, 1.625 \, k_0
\]
The simulated and measured reflection coefficients, showing good radiation efficiency in wide frequency band.
The measured near-field distributions (phases) and far-field radiation patterns of the proposed spoof SPP emitters, in which the beam deflection angles are $-22.5^\circ$, $-2^\circ$, and $16.1^\circ$. 
Amplification of SPP Waves

Amplification of SPP Waves

Measured Near Fields for SPP Amplification
Hybrid SPP-Integrated Circuits
Hybrid Passive and Active SPP Integrated Circuits

Zhang, Liu & Cui, unpublished, 2014
Monopole Excitation:

Simulation Results
Monopole Excitation:

Measured Results

Spoof Localized SPs

Measured Results

quadrupole
dipole
hexapole
eightpole
decapole
dodeca-pole
quattuordec-pole
Spoof Localized SPs

The spirally curved grooves make the ultrathin LSP structure more compact: with subwavelength scale. The right figure shows the electric and magnetic dipole resonances.

Huidobro, Shen et al., Physical Review X 4, 021003 (2014)
Electric Dipole

Magnetic Dipole

Power Flux

Far-Field Patterns

Near Fields

Electric Dipole

Magnetic Dipole
Subwavelength Spoof LSPs

Measurement Results
With the ultrathin planar or flexible structures, SPs will be practical in the microwave and terahertz frequencies.

We produced compact-size SPP waveguides and various passive devices.

We proposed the first SPP amplifier in the microwave frequencies, which is the basis to realize SPP circuits and systems.

We also produced subwavelength LSP sensors.
Thank you!

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