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High Excitation Efficiency of Channel Plasmon Polaritons in Tailored, UV-Lithography-Defined V-Grooves

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Abstract: We demonstrate >50% conversion of light to V-groove channel plasmon-polaritons (CPPs) via compact waveguide-termination mirrors. Devices are fabricated using UV-lithography and crystallographic silicon etching. The V-shape is tailored by thermal oxidation to support confined CPPs.

OCIS codes: (220.3740) Lithography; (230.7380) Waveguides, channeled; (240.6680) Surface plasmons

1. Introduction

Waveguide configurations based on surface plasmon polaritons (SPPs) possess unique scaling properties that allow one to concentrate light below the diffraction limit [1]. This feature of SPP-based waveguides has signaled the possibility of developing a new generation of subwavelength-integrated optical waveguides, circuits and devices. V-shaped grooves in metals supporting channel plasmon-polaritons (CPPs) represent a promising plasmonic waveguide configuration by providing a competitive confinement-loss tradeoff in addition to efficient broadband transmission around sharp bends. V-groove-supported CPPs have enabled the demonstration of compact plasmonic circuit components and novel nanofocusing elements [2]. However, the viability of plasmonic V-grooves for significant implementation requires a convenient approach to efficiently excite the CPP modes in a way that can be realized using affordable fabrication techniques.

CPP excitation to-date involves end-fire coupling, requiring a cleaved sample end-facet which may damage the waveguide entrance. This problem applies generally to SPP-based waveguide devices and has motivated the investigation of numerous directional nanoantenna configurations to conveniently launch plasmons via normally incident light, such as Yagi-Uda design, single element, phase-engineered, nanopatch and Bragg resonator type arrangements. Recently, Radko et al. developed a coupling arrangement to excite V-groove-supported CPPs via normally incident illumination by tapering the waveguide terminations to form angled nanomirrors [3]. These nanomirrors launched CPPs into nanoscale V-groove waveguides, yet the maximum in-coupling efficiency was ~10% and, like the arrangements mentioned above, required expensive and time-consuming fabrication methods such as focused ion beam milling or electron beam lithography.

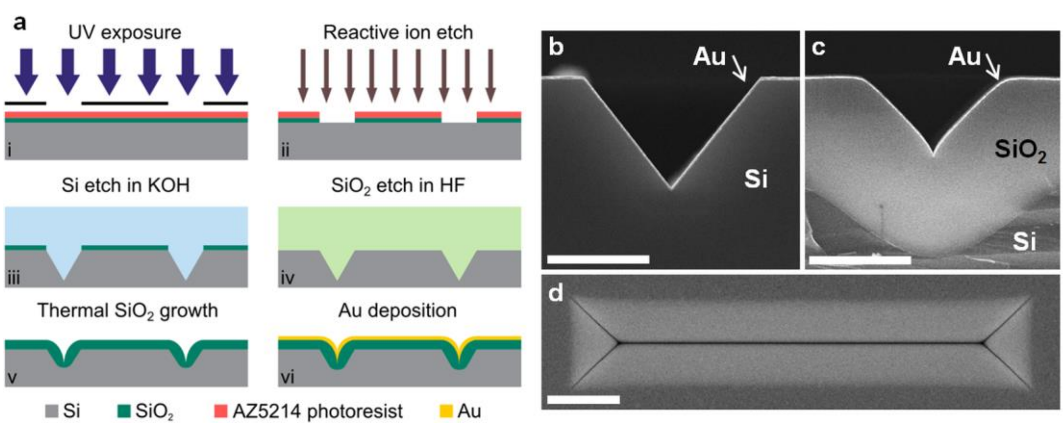

Fig. 1. (a) Fabrication procedure for Au V-grooves and coupling mirrors involving UV-lithography. (b)-(d) SEM images of resulting V-grooves, scale bars are 2 µm. (b) V-groove without thermal oxidation. (c) V-groove with a 2320 nm SiO_2 layer. (d) Top view of (c).

In this work, we experimentally demonstrate the >50% in-coupling efficiency of V-groove CPPs using freely propagating light directed at normal incidence onto waveguide-termination mirrors. The V-grooves and mirrors are both defined during the same conventional UV-lithography step which, combined with chemical etching of silicon crystallographic planes [4], forms the smooth, V-shaped profiles innately in a wafer-scale procedure. The silicon V-grooves are tailored by thermal oxidation of the silicon to sharpen the groove angle and ensure the existence of well-confined CPP modes. The experimental results are supported by finite element method (FEM) calculations.

2. Fabrication and Characterization

The fabrication of our V-grooves and waveguide-termination mirrors is shown in Fig. 1 [5]. The process involves UV-lithography to define the perimeter of the V-groove devices. A crystallographic wet etch of silicon planes forms the smooth V-groove sidewalls and mirrors simultaneously. A thermally grown silicon dioxide (SiO_2) layer on silicon modifies the V-shape geometry. A 70 nm gold layer is deposited to form the resulting plasmonic waveguide.

The device design is performed with 2D FEM calculations in COMSOL at a free space wavelength of $\lambda = 811$ nm [5]. The magnitude of the electric field distributions for fundamental plasmonic V-groove modes of different cross-sections are plotted in Figs. 2(b)-(c): (b) No oxide layer and (c) a 2320 nm SiO_2 layer. In Fig 2(b) it is evident that only wedge-based modes exist for the case without oxidation, whereas in Fig 2(c) the thermally grown SiO_2 layer sharpens the V-shaped profiles and increases the electric field confinement to a clear CPP mode.

To verify the calculations and determine the nature of the propagating modes, we illuminate V-groove waveguides with and without the SiO_2 layer, see Figs. 2(d)-(f) [5]. The V-groove device without SiO_2 layer (Fig. 2(d) only supports wedge-based modes. The device with SiO_2 layer (Fig. 2(e)) shows a clear single intensity peak with an in-coupling efficiency of >50%. Rotating the polarization 90° (Fig. 2(f)) results in a factor of 10 reduction in out-coupled light, supporting the assumption that it is a TE-like CPP mode with weak longitudinal component.

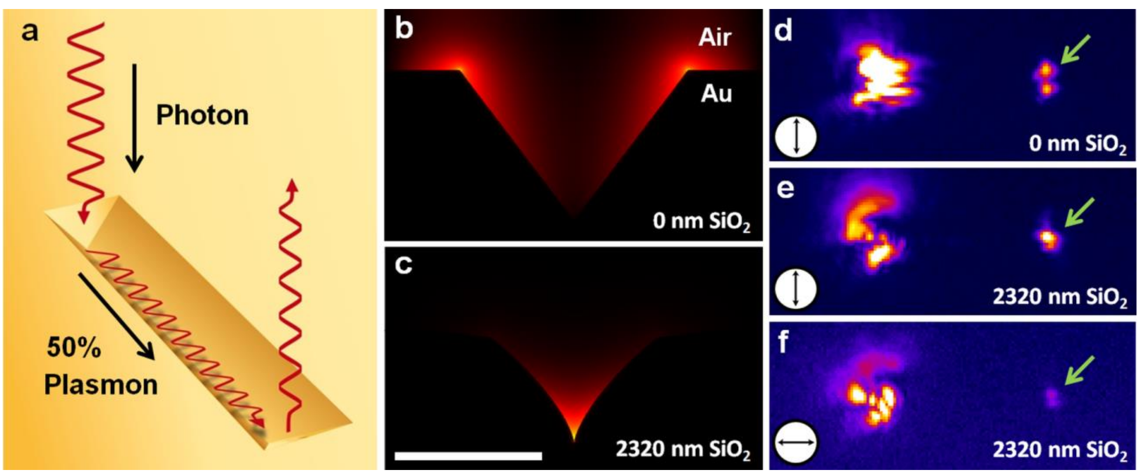

Fig. 2. (a) Illustration of the in- and out-coupling of light in the V-groove devices. (b)-(c) 2D FEM calculations of the electric field for different V-groove cross-sections. Scale bar is 2 µm. (d)-(f) Experimentally observed radiation from V-groove samples. Circular inset denotes the incident electric field polarization. SiO_2 layer modification alters the propagating mode distribution. The polarization dependence indicates a CPP mode.

In summary, we demonstrate the highly efficient (>50%) conversion of freely propagating light to V-groove channel plasmon-polaritons (CPPs) via compact waveguide-termination mirrors. The devices are fabricated using UV-lithography and crystallographic silicon etching, pointing to wafer-scale production. The V-shape is tailored by thermal oxidation to support confined CPPs. The coupling configuration is ideal for efficient excitation of plasmonic elements collinear through a microscope objective, such as for integrated lab-on-a-chip devices, or for facilitating efficient inter- and intra-chip communication in planar or multi-leveled photonic information processing systems.

3. References

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