Thermo-Optically Tunable Flat-Lenses at Near Infrared Wavelengths

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Abstract - We present a slot-grating flat lens fabricated in thin layers of amorphous silicon-on-aluminum. The structures are designed to collimate the light propagating through the slot at $\lambda=833$nm and 1550nm. The high dependency of refractive index on temperature for amorphous silicon has the potential to enable thermo-optic focusing and steering.

Nanostructuring a metal surface with a periodic grating opens up bandgaps in its dispersion diagram and as long as the operation wavelength is close to one of these bandgaps, where the dispersion curve deviates from the light line in the dielectric, the confinement of the surface plasmon polaritons (SPPs) will be improved. This type of structure is especially important beyond visible wavelengths where SPPs are very weakly confined on planar metal/dielectric interfaces due to their very small decay length in the dielectric normal to the interface. The second role of the grating is to scatter a proportion of the confined light at each period so that the scattered light from each period is in phase and also in phase with the light directly passing through the aperture. These structures have been shown to greatly reduce divergence from tens of degrees to only a few without excessively effecting the overall transmission [1-4]. However, in this configuration the grating is fixed and there is no variable parameter that would allow steering of a beam with a constant wavelength. A further method of increasing the so called SPP coupling efficiency – the ratio of the light coupled into the aperture mode that is then coupled into the SPP mode – is by adding a thin dielectric layer onto the surface of the noble metal [5]. By adding the higher refractive index dielectric layer and varying its thickness, $t_S$, the effective wave vector of the SPP mode can be tuned such that the wave vector matching condition between the SPP and the light diffracted by the aperture is achieved. This enables efficient coupling of light from the slit into a hybrid-SPP-waveguide-mode (HPWG mode) on the adjacent metal surface and increases light confinement to the surface from only a few percent to nearly forty percent at both $\lambda=833$nm and 1550nm. Crucially, if we add the fixed geometrical grating into the surface a dielectric material, where if this material has a relatively high $dn/dT$ such as Si or Ge then we have a structure where $\lambda_{SPP}$ is tunable with temperature. In Si, the change in $n$ induced by heating from room temperature to 400°C is ~0.1 and is an approximately linear change [6]. Lumerical Finite-Difference Time-Domain (FDTD) [7] simulations in Fig. 1(a), (b) & (c) show that due to the increased refractive index, the wavelength of the HPWG mode is shortened at the Al/Si interface and the fixed grating will no longer collimate the light in the far-field. This follows the explanation we have outlined in Pugh et al [3]. Focused Ion Beam (FIB) fabricated devices are currently undergoing measurement using the Fourier Image Spectroscopy (FIS) technique.
The structure is a 200nm thick ($t_{Al}$) Al layer with a varying thickness ($t_{Si}$) Si layer on top – 210nm for $\lambda=833$nm device in (a&b) and 360nm for $\lambda=1550$nm device in (c&d). Light travels through an aperture 300nm wide ($w$) for the $\lambda=833$nm device, where the grating slots are 160nm deep ($h$) by 100nm wide ($d$), where the distance from the aperture center to the edge of the 1st grating period, $s=1.03\mu m$ and the remaining grating period, $p=810$nm. For the $\lambda=1550$nm device, these parameters are $w=500$nm, $h=250$nm, $d=150$nm, $s=0.885$ and $p=1550$nm. Light scattered from the grating is shown in the $|E|$-field snapshot in (a), (b), (c) and (d) where $n_{Si}$ is 2.458, 2.708, 2.344 and 2.444 respectively. The far-field angle distributions are shown in (e).

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