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In the above communication, we have investigated in details the possibility of observing a large negative lateral Goos–Hanchen (GH) shift from p-polarized light at long wavelength incident onto a bare metal surface, at angles close to grazing incidence. The shift could be up to a few wavelength (e.g. \(\frac{\lambda}{240}\) at a wavelength of 3390 nm onto silver) and the possible presence of a “pseudo Brewster angle” will not hinder the observability of such an effect. This effect has since been verified experimentally via reflection of IR light from a gold surface [1].

In reviewing the literature, aside from pointing out that our results were in consistency with those hinted at from previous analysis of surface backward waves [2] and of negative energy flow at interface [3], we should have also noted the first explicit calculation by Wild and Giles of such GH shifts at a silver surface which had obtained a (albeit small) negative shift in the order of one wavelength \(\frac{\lambda}{0.5}\) [4].

In addition, we would like to emphasize that such large negative GH shift at a metal surface can easily be understood by examining the well-known elementary boundary conditions for the fields across an interface, as applied to the discussion of the continuity of the various components of the Poynting vector in [3].

In fact, if we let the \(x-z\) plane be the plane of incidence and apply the following boundary conditions for the normal (N) and tangential (T) field components at the vacuum–metal interface (assuming non-magnetic materials so that \(B = H\) and neglecting damping):

\[
E_{\Omega N} = eE_N, \quad E_{\Omega T} = E_T, \quad H_{\Omega N} = H_N, \quad H_{\Omega T} = H_T
\]

(1)

we derive immediately, as in [3], the continuity of the energy flow along the interface described by the component of the Poynting vector \(S_x \sim (\mathbf{E} \times \mathbf{H})_x = E_xH_y\) for s-polarized wave; and by the quantity \(eS_x \sim -eE_xH_y\) for p-polarized wave. Hence we conclude that while there is always a positive GH shift in the s-polarized case, \(S_x\) changes by a sign in the p-polarized case when \(e < 0\) as is the case when the incident frequency is below the plasmon frequency of the metal. This then leads to a negative GH shift [3].

Thus, following the above scheme of thought, one can easily understand how the negative GH shift in metal arises and how such shift can be manifested for p-polarized light, large incidence angle (i.e. close to grazing incidence so that \(E_z\) will be large), low incident frequency (so that \(e\) will be more negative), and metal with high plasmon frequency (e.g. aluminum). In addition, one can also extend the above arguments to the case of meta-materials instead of metal where the magnetic permeability can also turn negative [by distinguishing the \(B\) field and \(H (=B/\mu)\) in (1)]. In this case, it is the continuity of \(\mu S_x \sim \mu E_xH_y\) for s-polarized waves, implying that even the s-polarized light will experience negative GH shifts as has been reported in the literature [5]. Along the same line, one can even go further to design interfaces made of different combination of ordinary and meta-materials so that various positive/negative GH shifts may be generated as desired.

We believe the above remarks should help to shed some light on the recently observed negative GH shifts at a bare metal surface [1].

References

and there was no elaboration for the possibility of observing a much larger negative shift in the metal case, without the possible hindrance by the presence of the “pseudo Brewster angle” as was clarified in our recent work.