Quality of Mid-IR Plasmon Resonances in Highly Mismatched Alloys

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Highly mismatched alloys (HMAs) – semiconductors where the alloying element has highly different electronegativity from the host semiconductor elements – are used in solar cells and laser diodes due to their highly tunable band gaps. In HMAs with conduction band (CB) anticrossing, the CB splits into E_+ and E_- bands, described by the band anticrossing model, with most past interest focused on the rapid change of E_- with alloy fraction. When doped so that the E- band is occupied, it was recently shown that the tunability of HMAs allows them to have plasmon resonances in the THz to mid-IR range [1]. We evaluate the potential of HMAs for mid-IR plasmonics by predicting their bulk plasmon frequency and associated losses.

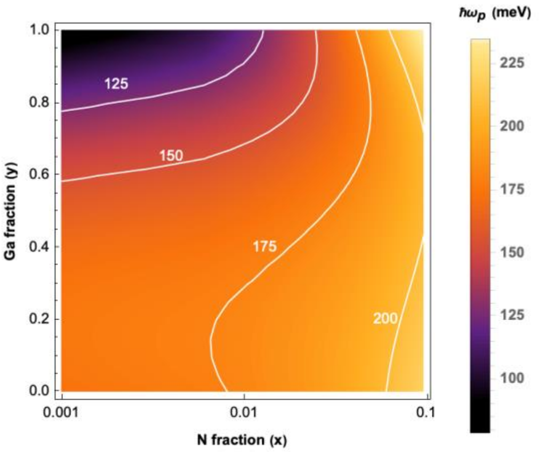

Fig.1. Bulk plasmon frequency of $Ga_yIn_{1-y}As_{1-x}N_x$ with a 30% full E_- band for varying Ga fraction and N fraction (alloying element).

We characterize the quality of the plasmon resonance using a figure of merit $|\chi|^2/\mathrm{Im}\chi$, where χ is the electric susceptibility, which describes the potential of a material to scatter or absorb light [2]. We use a Green's function method based on the coherent potential approximation to develop a theory for the conductivity, and in turn the susceptibility, of the entire family of HMAs with CB anticrossing. The imaginary part of the susceptibility describes losses in the material. We use a relaxation time approximation or Drude model of the conductivity to represent those losses, with scattering times extracted from mobility measurements [3-7].

Using parameters extracted from a range of HMAs, we find that doped HMAs support a wide range of bulk plasmon frequencies up to approximately 200 meV, as in the example in Fig. 1, with some giving quality factors competitive with other leading mid-IR plasmonic materials [Fig. 2]. The plotted curves are only for HMA compositions and carrier concentrations where the mobility has been measured, so higher quality factors are almost certainly possible. In the mid-IR region, wavelength $\lambda < 5\ \mu\mathrm{m}$, HMAs may be the best available materials.

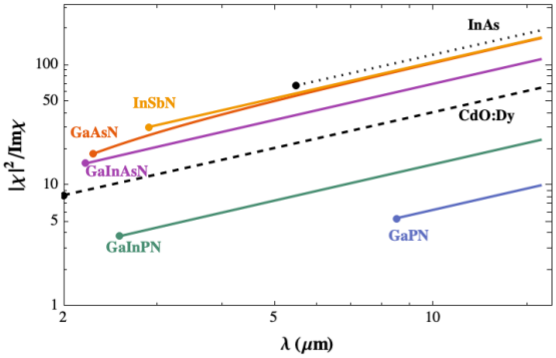

Fig.2. Drude model figure of merit vs. wavelength for a variety of HMAs with fixed compositions and carrier concentrations (coloured lines) and competing materials (black lines). Markers indicate figures of merit at bulk plasmon wavelengths and lines indicate figures of merit at potential surface plasmon wavelengths from structured materials.

References

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