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Stockman Responds to Comment by Wuestner et al.

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In their Comment¹ Wuestner et al. state that in our Letter², the quasistatic approximation (QSA) “...is inherently unsuitable for a comparative study of these [loss compensation and spasing - MIS] thresholds due to the a priori neglect of radiation...” Here we claim that this Comment and the original article³ contain errors and are invalid, and that the results of Ref. 2 are correct.

A particular point of misplaced contention by Wuestner et. al.¹ is that our approach “...does not apply to realistic optical metamaterials in general and to the fishnet structures considered in Ref. 3 in particular.”

By a “realistic” metamaterial Wuestner et. al. understand something that is not a metamaterial. The fishnet nanostructures treated in many publications, including Refs. 3–5, are not metamaterials since the unit cell size $a = 280$ nm (Refs. 3–5) is close to the Bragg spacing $\lambda/2$ in the visible. (Note that there are fundamental limitations on a for magnetic-response metamaterials established in Ref. 6.) The lattice constant a comparable to λ leads to very strong spatial dispersion that limits the maximum wave vector $\mathbf{k}$ and causes the Landau damping and loss of the super-resolution,^{7,8} compromising the very reason why such materials might be of interest.

A metamaterial is defined to be three-dimensional (3d) to enable optical elements such as “superlenses”, etc. The fishnet systems in Refs. 3–5 are structured nanofilms. As such, they cannot be characterized by permittivity. Stacking the nanofilms into a 3d system would fundamentally change their optical properties due to near-field interactions between the layers in the stack. Usable optical elements, such as lenses or prisms, cannot be fabricated from them, and none has so far been. Our theory^{2,9} does not directly apply to such nanofilms, as has been stated

in Ref. 2.

This confusion between metamaterials and nanofilms leads Wuestner et al. in Ref. 1 to emphasize that “...radiative loss marks the difference between lasing and amplification thresholds...” In fact, a plasmonic nanofilm above threshold may function as a lossy spaser, which can amplify or generate just as a spaser with saturable absorber does in Ref. 10. But it is not a metamaterial and not a laser. Also, it is unstable with respect to in-plane spasing and spontaneous emission amplification.

In contrast, a 3d periodic metamaterial is a plasmonic-photonic crystal where the eigenmodes are Bloch functions¹¹, which on a lattice period only acquire a phase while their magnitude is periodic. This is Bloch’s theorem that implies that no loss (radiative or otherwise) is associated with propagation on a periodic lattice.

A significant number of generating spasers have been reported in experiments.^{12–16} In contrast, in metamaterials despite a large effort to compensate loss by gain, there has been very little progress. There has been only one success claimed in Ref. 4 for a system that is actually not a metamaterial. There have also been multiple unsuccessful attempts at full loss compensation for SPPs.^{17–20} One may speculate this to be caused by unintended spasing in the SPP propagation plane.

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