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Title:
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Date:
2021-05-01

Citation:
Wen, D., Cadusch, J. J., Fang, Z. & Crozier, K. B. (2021). Reconsidering metasurface lasers. Nature Photonics, 15 (5), pp.337-338. https://doi.org/10.1038/s41566-021-00806-x.

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https://hdl.handle.net/11343/294847

Reconsidering metasurface lasers

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Metasurface based orbital angular momentum (OAM) generation has attracted considerable attention recently[1, 2, 3, 4, 5, 6, 7]. The recently published article "*High-purity orbital angular momentum states from a visible metasurface laser*" presents a very neat method for orbital angular momentum (OAM) optical state generation[8]. However, we suspect that the explanation of the operating principle provided by the authors is incorrect or incomplete. We anticipate that this could hamper future progress in not only metasurface lasers but also metasurfaces in general if left uncorrected.

As we understand it, the authors intend to generate a resonant cavity mode, which should have the same state after one round trip within the cavity. To explain this point, the authors state that "*Starting as |H, 0> (horizontally polarized and no OAM), it is converted to the desired combination within the laser, say cos θ |H, l_1> + sin θ |V, l_2>….On reflection from the output coupler mirror back to the J-plate, the state is cos θ |H, -l_1> + sin θ |V, -l_2>. From the reciprocity of the metasurface, the initial state |H, 0> is regained, which then returns through the polarizer to the KTP crystal*". We agree that, after the reflection from the output coupler mirror, the state changes to cos θ |H, -l_1> + sin θ |V, -l_2>. However, **the initial state |H, 0> cannot be regained by what the authors refer to as "the reciprocity of the metasurface"** because the presence of the J-plate within the cavity will change the state to *cos θ |H, -2l_1> + sin θ |V, -2l_2>,* rather than back to the initial OAM state. We explain our point below.

Throughout this Comment, we take JP1(in the nomenclature of the authors) as an example upon which all discussions are based. We also assume that the fast axis of the J-plate is along the vertical direction (φ=90° in Fig. 1). We take the polarization of the incident light as being horizontal. Therefore, we do not need to consider the phase retardance between the fast and slow axes of the waveplate. An OAM beam with l=1 will be generated according to the JP1 design. After the horizontally polarized beam with no OAM (E_0) is transformed by the J-plate (from area A to area B in Fig.1), the field will have the following form in the *xyz* coordinate system. Note that, as discussed, the field is *x*-polarized.

$$E_1 = E_0 \exp[i * \varphi(x, y)] \quad (1)$$

where we have z=0 here and φ (x, y) represents the azimuthal angle of the point (x, y). The beam travels the distance Δz in area B and approaches the mirror. Then the field becomes

$$E_2 = E_0 \exp[i * \varphi(x, y) + ik\Delta z\ ] \tag{2}$$

Where $k=2\pi/\lambda$. The expression for E_2 is still expressed in the xyz coordinate system. After E_2 is reflected by the mirror, the propagation directed is reversed (from z to z' direction). We thus use the $x'y'z'$ coordinate system. The azimuth angle φ' (x', y') has the following relationship with φ (x, y)

$$\varphi\ (x, y) = \pi - \varphi'\ (x', y') \tag{3}$$

This can be easily verified, for example, we have φ=45° as shown in the xyz coordinate system which corresponds to φ'=135° in the new $x'y'z'$ coordinates (Fig.1). We rewrite E_2 in the $x'y'z'$ system and find

$$E_2 = -E_0 \exp[-i * \varphi'(x', y') + i\pi\ + ik\Delta z] \tag{4}$$

This demonstrates that we have an OAM beam with l= -1 in the $x'y'z'$ coordinate system. This agrees, so far, with the authors' description. On the return trip, the phase change caused by the J-plate is also rewritten in the $x'y'z'$ coordinates as

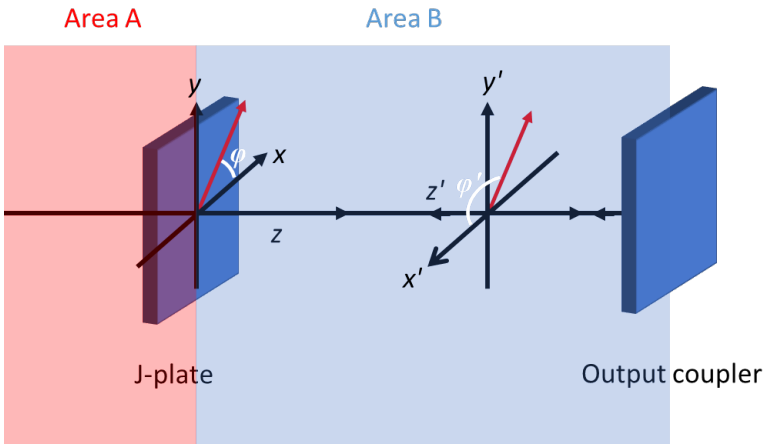
$$\Phi(x', y') = \pi - \ \varphi'\ (x', y') \tag{5}$$

The field after passing through the J plate again (from area B to area A) is thus given by:

$$\begin{aligned} E_3 = E_2 e^{ik\Delta z} e^{i\Phi(x', y')} &= -E_0 \exp[-i * 2\varphi'(x', y') + i2\pi\ + i2k\Delta z] \\ &= -E_0 exp[-i * 2\varphi'(x', y')] * exp[2i(\pi + k\Delta z)] \end{aligned} \tag{6}$$

We abandon the term $exp[2i(\pi + k\Delta z)]$ since it does not depend on lateral coordinates (x', y'). Therefore, this field (E_3) **has a topological charge of -2, instead of 0 as mentioned by the authors**. Since the J-plate works in a manner of traditional spiral phase element here, our point is also consistent with the analysis of previous works[6, 9]. This explanation also applies when the fast axis of the J-plate is aligned along other angles.

In summary, we conclude that the explanation of the operating principle presented in the original paper is incorrect or incomplete. That paper however reported experimental results, so we anticipate that there must be **another mechanism at play** that allows the round trip condition to be met and the metasurface laser to operate.



Competing interests

The authors declare no competing interests.

References

1. Li G, Kang M, Chen S, Zhang S, Pun EY-B, Cheah KW, *et al.* Spin-Enabled Plasmonic Metasurfaces for Manipulating Orbital Angular Momentum of Light. *Nano Lett.* **13**, 4148-4151 (2013).

2. Pu M, Li X, Ma X, Wang Y, Zhao Z, Wang C, *et al.* Catenary optics for achromatic generation of perfect optical angular momentum. *Sci. Adv.* **1**, e1500396 (2015).

3. Yang Y, Wang W, Moitra P, Kravchenko II, Briggs DP, Valentine J. Dielectric Meta-Reflectarray for Broadband Linear Polarization Conversion and Optical Vortex Generation. *Nano Lett.* **14**, 1394-1399 (2014).

4. Karimi E, Schulz SA, De Leon I, Qassim H, Upham J, Boyd RW. Generating optical orbital angular momentum at visible wavelengths using a plasmonic metasurface. *Light Sci. Appl.* **3**, e167 (2014).

5. Huang C, Zhang C, Xiao S, Wang Y, Fan Y, Liu Y, *et al.* Ultrafast control of vortex microlasers. *Science* **367**, 1018-1021 (2020).

6. Maguid E, Chriki R, Yannai M, Kleiner V, Hasman E, Friesem AA, *et al.* Topologically Controlled Intracavity Laser Modes Based on Pancharatnam-Berry Phase. *ACS Photonics* **5**, 1817-1821 (2018).

7. Stellinga D, Pietrzyk ME, Glackin JME, Wang Y, Bansal AK, Turnbull GA*, et al.* An Organic Vortex Laser. *ACS Nano* **12**, 2389-2394 (2018).

8. Sroor H, Huang Y-W, Sephton B, Naidoo D, Vallés A, Ginis V*, et al.* High-purity orbital angular momentum states from a visible metasurface laser. *Nat. Photonics* 1-6 (2020).

9. Oron R, Davidson N, Friesem AA, Hasman E, Wolf E. Transverse mode shaping and selection in laser resonators. *Prog. Opt* **42**, 325-386 (2001).