Supplementary Information

Generation of Polarization-Multiplexed Orbital Angular Momentum Combs *via* All-Silicon Terahertz Metasurfaces

Ming-Zhe Chong [1], *Yiwen Zhou* [2], *Zong-Kun Zhang* [1], *Jin Zhao* [1,3], *Yue-Yi Zhang* [1,3], *Chong-Qi Zhang* [1], *Xiaofei Zang* [2]*, *Chao-Hai Du* [1,3]*, *Pu-Kun Liu* [1,3]†, *Ming-Yao Xia* [1]

[1] School of Electronics, Peking University, Beijing 100871, China

[2] Terahertz Technology Innovation Research Institute, and Shanghai Key Lab of Modern Optical System, University of Shanghai for Science and Technology, No. 516 JunGong Road, Shanghai 200093, China

[3] State Key Laboratory of Advanced Optical Communication Systems and Networks, School of Electronics, Peking University, Beijing 100871, China

* Correspondence: *Xiaofei Zang*: xfzang@usst.edu.cn, *Chao-Hai Du*: duchaohai@pku.edu.cn.

† Deceased, October 2023.

A. Discussion about the sizes of meta-atoms.

Firstly, the height h of all meta-atoms is 400 μm. The main reason for this is to get a wider transmission phase covering range as transverse sizes (W and L) change. To be specific, according to effective waveguide theory, a meta-atom can be seen as a waveguide, whose transmission phase can be expressed as $\phi = \frac{2\pi}{\lambda} n_{eff} h$, where λ is the wavelength, n_{eff} is the effective refractive index decided by transverse sizes (W and L), h is the height of silicon pillars. Thus, if h is larger, ϕ will change faster for a meta-atom with the same W and L. This is to say, we can easily achieve the whole 2π covering of ϕ as W and L vary within a period p = 120 μm. Despite this, h should not be too large. A very large aspect ratio (h/W) will be a challenge for the fabrication process. Considering both aspects, we set h to be 400 μm.

Next, we will consider the selection of W and L of meta-atoms. Generally, the target field distributions generated from the metasurfaces will accord better with the theoretically designed ones, when the phase gradient of each meta-atom is smaller. A smaller phase gradient represents a better accuracy.

However, there are limitations to making it too small. Firstly, an excessively small phase gradient cannot be physically realized. When the phase gradient between two adjacent meta-atoms is excessively small, their spatial sizes can also be extremely similar. Such a small difference is too challenging for the fabrication process. Secondly, the excessively small phase gradient is a burden for the numerical simulation. In order to achieve it, the difference between spatial sizes of each meta-atom will be too small. Therefore, the number of size parameter sweepings for the meta-atom design will be too large.

In this work, the phase gradient is 30° to achieve a satisfying accuracy. At the same time, the phase gradient of 30° exactly corresponds to the meta-atom spatial size gradient of 1 μm (detailed sizes are shown in Table S1), which is also the resolution of the fabrication process. Thus, these meta-atoms can be fabricated, while the difficulty of the parameter sweeping is acceptable.

Table S1. Sizes (*W* and *L*) of selected 144 meta-atoms (unit: μm).

(*W*, *L*)		ϕ_{xx}											
		-180°	**-150°**	**-120°**	**-90°**	**-60°**	**-30°**	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**
ϕ_{yy}	**-180°**	(55, 55)	(49, 57)	(41, 62)	(32, 69)	(94, 45)	(88, 46)	(82, 47)	(77, 48)	(73, 49)	(69, 50)	(65, 51)	(60, 53)
	-150°	(57, 49)	(51, 51)	(43, 54)	(34, 60)	(102, 39)	(95, 40)	(89, 41)	(83, 42)	(78, 43)	(73, 44)	(68, 46)	(63, 47)
	-120°	(62, 41)	(54, 43)	(46, 46)	(36, 51)	(70, 81)	(104, 34)	(98, 34)	(91, 35)	(85, 36)	(80, 37)	(74, 38)	(68, 40)
	-90°	(69, 32)	(60, 34)	(51, 36)	(40, 40)	(72, 77)	(68, 79)	(65, 81)	(62, 82)	(59, 84)	(56, 87)	(53, 89)	(49, 93)
	-60°	(45, 94)	(39, 102)	(81, 70)	(77, 72)	(73, 73)	(70, 75)	(66, 77)	(63, 78)	(60, 80)	(57, 82)	(54, 85)	(50, 88)
	-30°	(46, 88)	(40, 95)	(34, 104)	(79, 68)	(75, 70)	(71, 71)	(68, 73)	(64, 75)	(61, 76)	(58, 78)	(55, 80)	(51, 83)
	0°	(47, 82)	(41, 89)	(34, 98)	(81, 65)	(77, 66)	(73, 68)	(69, 69)	(66, 70)	(62, 72)	(59, 74)	(56, 76)	(52, 78)
	30°	(48, 77)	(42, 83)	(35, 91)	(82, 62)	(78, 63)	(75, 64)	(70, 66)	(67, 67)	(64, 68)	(60, 70)	(57, 72)	(53, 74)
	60°	(49, 73)	(43, 78)	(36, 85)	(84, 59)	(80, 60)	(76, 61)	(72, 62)	(68, 64)	(65, 65)	(61, 67)	(58, 68)	(54, 70)
	90°	(50, 69)	(44, 73)	(37, 80)	(87, 56)	(82, 57)	(78, 58)	(74, 59)	(70, 60)	(67, 61)	(63, 63)	(59, 64)	(55, 66)
	120°	(51, 65)	(46, 68)	(38, 74)	(89, 53)	(85, 54)	(80, 55)	(76, 56)	(72, 57)	(68, 58)	(64, 59)	(61, 61)	(57, 62)
	150°	(53, 60)	(47, 63)	(40, 68)	(93, 49)	(88, 50)	(83, 51)	(78, 52)	(74, 53)	(70, 54)	(66, 55)	(62, 57)	(58, 58)

B. Details about the fabricated samples.

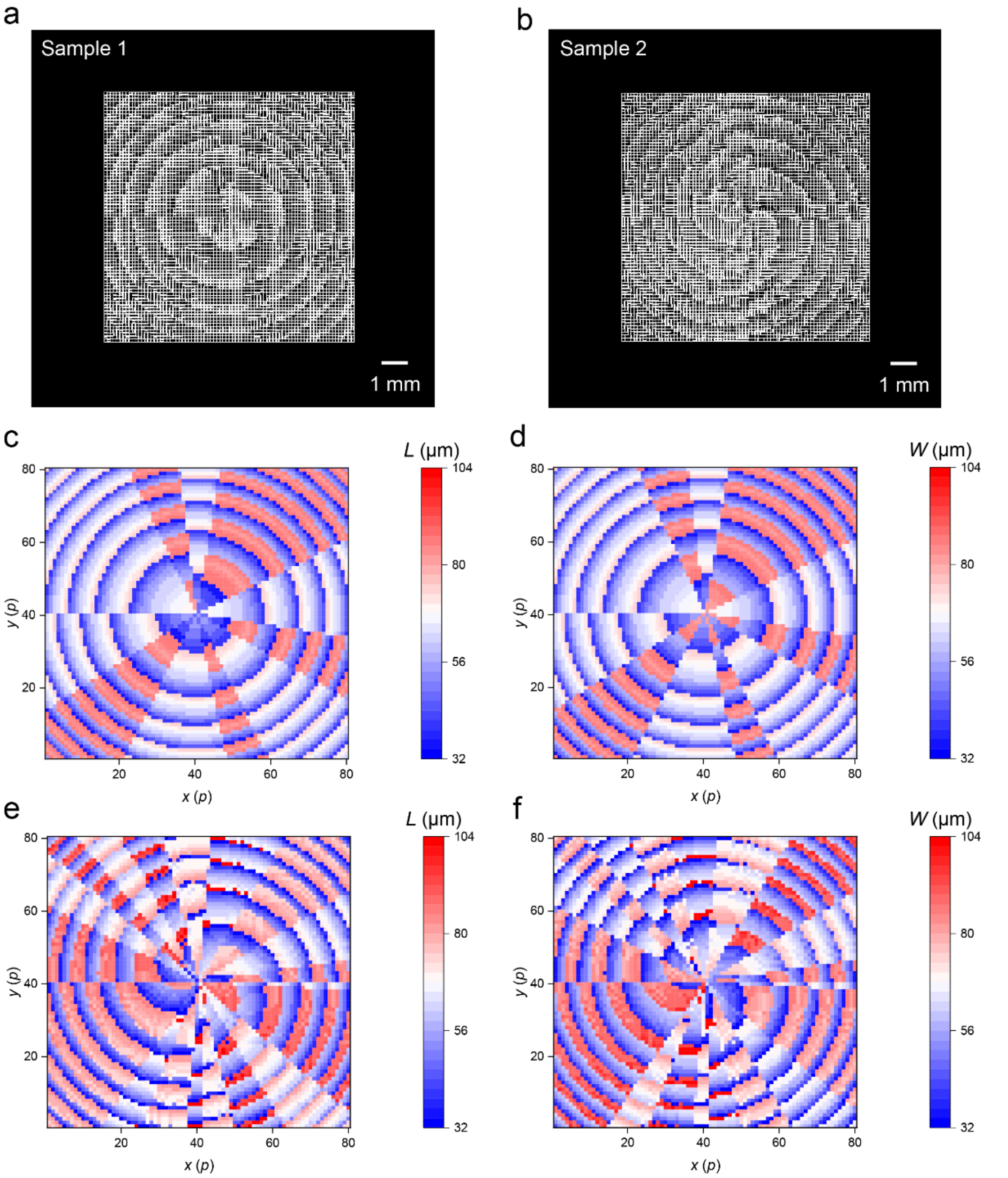

Figure S1. (a, b) Schematic of fabricated (a) sample 1 and (b) sample 2. (c-f) Lengths (*L*) and widths (*W*) of all the meta-atoms in (c, d) sample 1 and (e, f) sample 2.

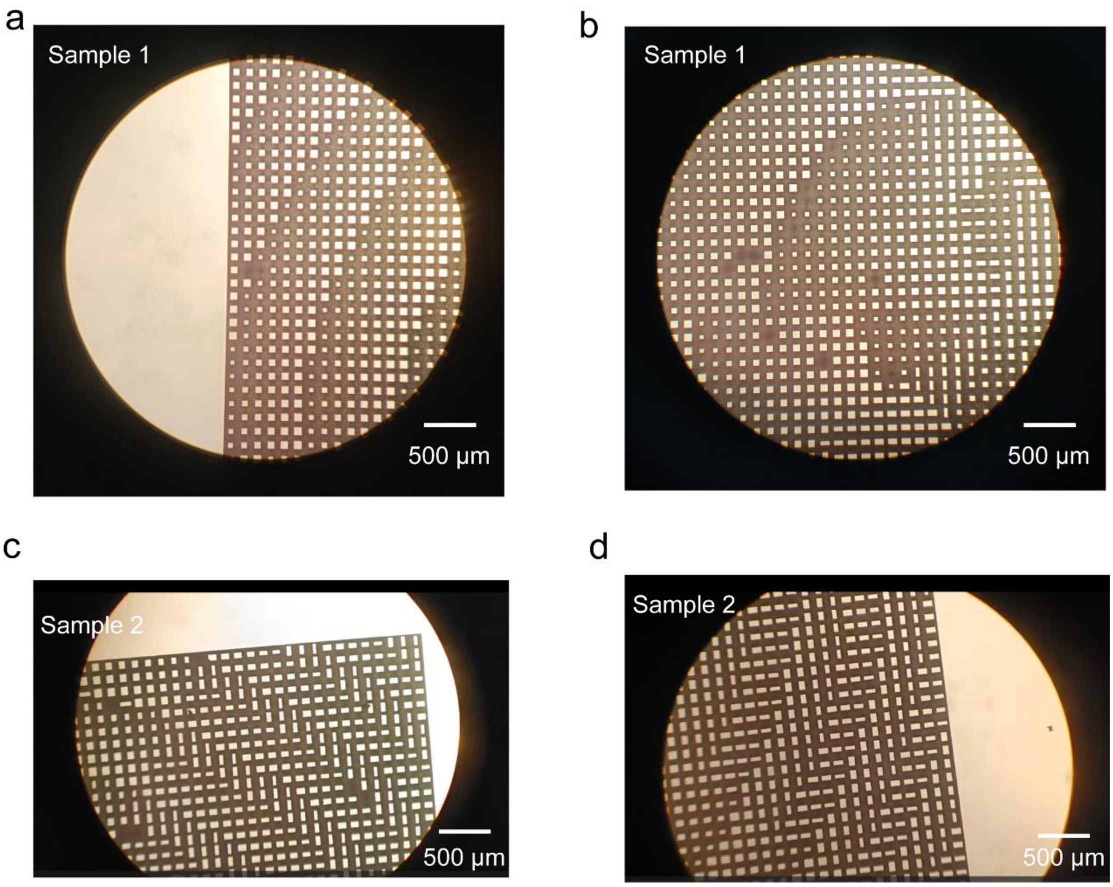

Figure S2. More photos about (a, b) sample 1 and (c, d) sample 2.

C. Discussion about the difference between simulated and measured results.

There are some reasons leading to the difference between simulated and measured results.

1). The profile of the incident wavefront is not perfect in the experiment. Theoretically, the incident wavefront should be a plane wave. However, the incident wavefront may be quasi-gaussian with a tilt and uneven profile in the measurement equipment.

2). The distance between the samples and the detection plane may not perfectly be 7.5 mm. The detection plane is the focal plane, so the deviated detection plane may cause the different beam sizes between measured and simulated results. Besides, the off-focus deviation can cause a larger phase error.

3). The scanning step (200 μm in Figure 4c and 100 μm in Figure 4d) is too large. Thus, the resolution is not high enough and the detailed information may be missing.

4). The size of the detection area is not big enough. There is still some energy of the THz beam outside the detection area. This energy is ignored, so the intensities of some high-order OAM modes are lower than those in the simulation.

5). Some fabrication errors also cause this. Due to the limit of the DRIE process, the depths of different meta-atoms (with different widths and lengths) slightly vary. Thus, the transmission phase distributions of the fabricated samples are slightly different from the desired ones. Besides, several silicon pillars collapse, which also affects the phase pattern of the metasurfaces.

As a result, these factors cause the uneven intensity of OAM modes in the experiment. In the future, we plan to improve the fabrication and measurement processes to achieve better experimental results.