Supporting Information

Broadband mid-infrared metalens with polarization-controlled at-will chromatic dispersion

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S1. Method for the design of broadband high efficiency at-will chromatic dispersion metalenses

As described in the main text, to achieve broadband metalenses with arbitrary chromatic dispersion of orthogonal polarization states, the phase ϕ and phase dispersion $(\partial\phi/\partial\omega)$ should be controlled simultaneously. The phase dispersions between 3.75 μm to 4.75 μm is obtained by linearly fitting the phase spectrum of the meta-atoms. The linear fitting with high *R*-squared values is preserved to construct a mapping relationship between phase and dispersion of the birefringent all-Si meta-atoms to establish a database (Fig. S1). An optimal algorithm is designed to scanning the whole database to get the optimal set $(\phi_x, \frac{\partial\phi}{\partial\omega}|_x, \phi_y, \frac{\partial\phi}{\partial\omega}|_y)$ at each pixel coordinate (x, y) on the broadband polarized-dependent at-will chromatic dispersion metalenses.

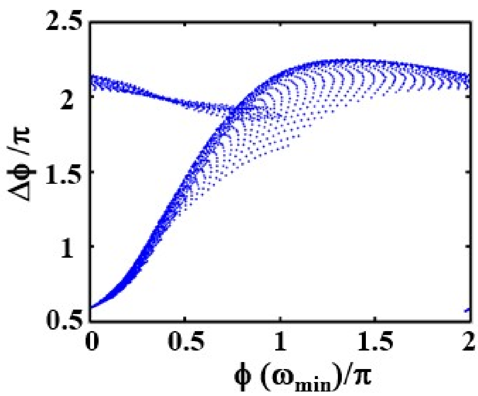

Fig. S1. The simulated phase-dispersion library. The dispersion is $\Delta\phi = (\partial\phi/\partial\omega)\cdot(\omega_{max}-\omega_{min})$, and $\phi(\omega_{min})$ is the phase of the lowest frequency with $\omega_{max} = 2\pi/\lambda_{min}$ and $\omega_{min} = 2\pi/\lambda_{max}$. Here, the maximum wavelength is λ_{max}=4.75 μm, and the minimum wavelength is λ_{min}=3.75 μm.

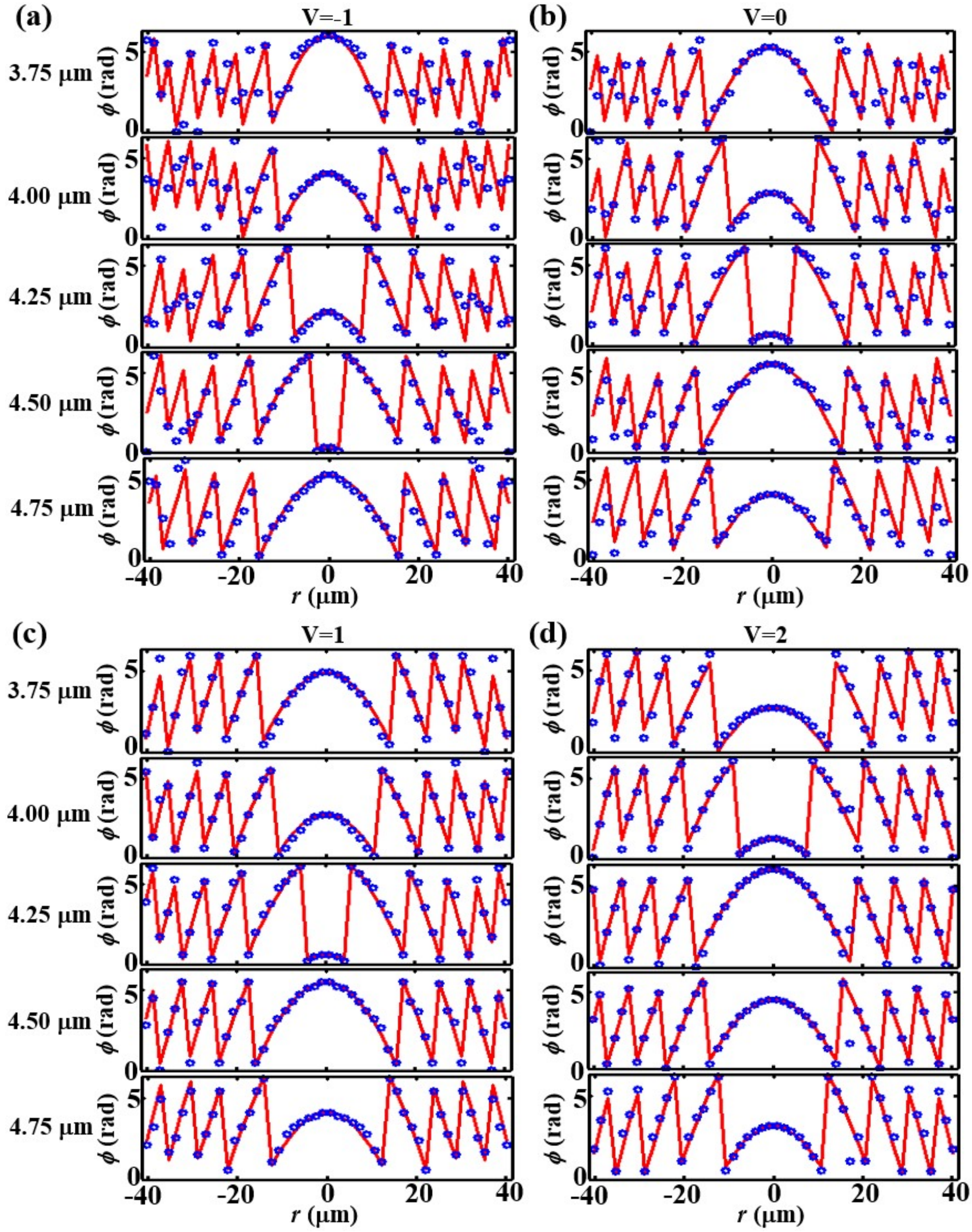

Fig. S2. The required and achieved phase profiles for the designed BACDPIMs for the *x*-polarization. (a) Positive dispersion, (b) dispersionless, (c) regular (negative) dispersion, and (d) hyper-dispersion of the designed BACDPIMs.

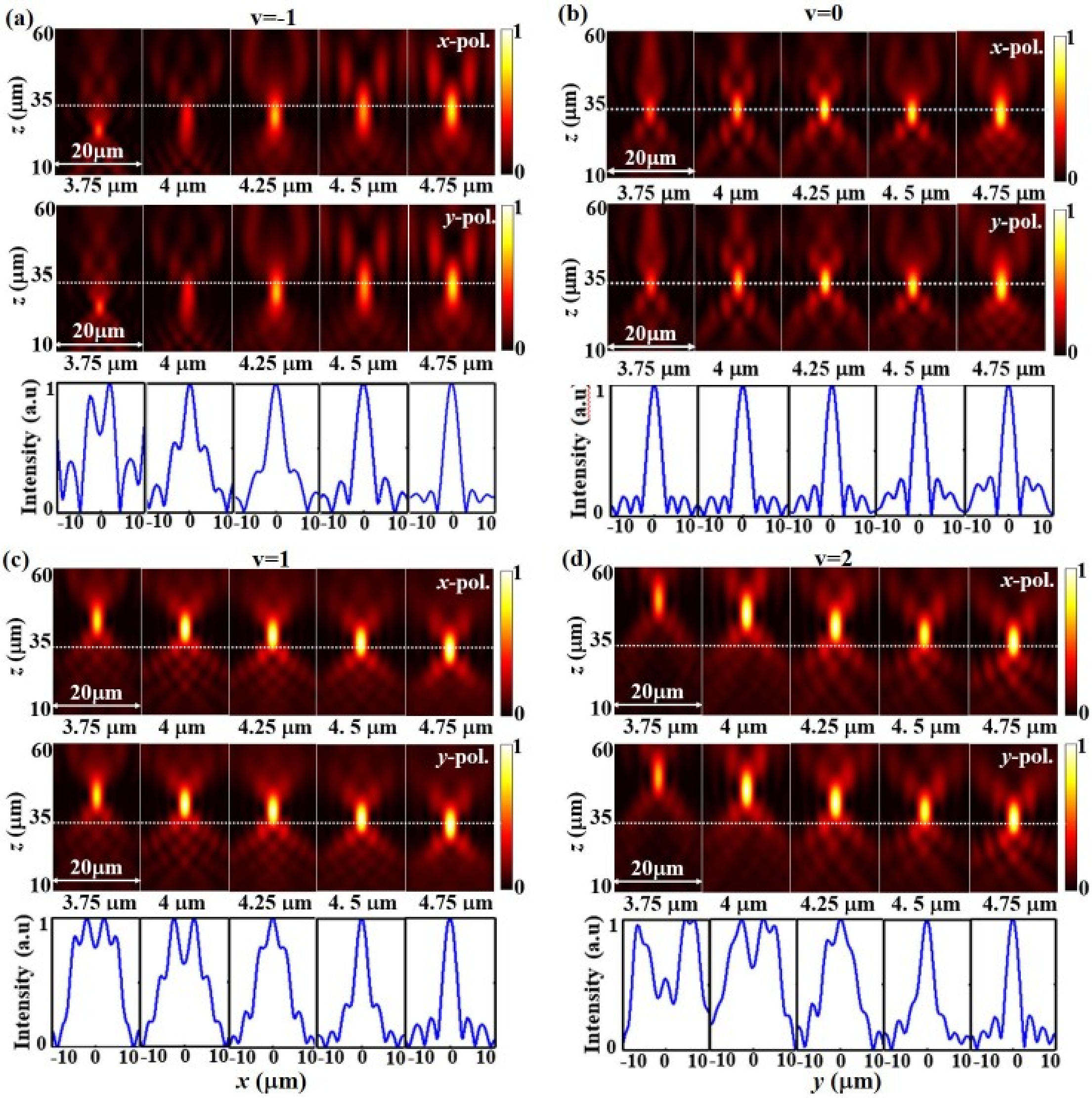

Fig. S3. Simulated results of the designed BACDPIM. The BACDPIMs are designed at a basic wavelength λ=4.75 μm with focal length *f*=30 μm. (a) Positive dispersion metalens, (b) zero dispersion metalens, (c) regular (negative) dispersion metalens, and (d) hyper-dispersion metalens. The top panel is the intensity profiles in the *x-z* plane for the *x*-polarized incidence, the middle panel is the intensity profiles in the *y-z* plane for the *y*-polarized incidence, and the bottom panel is the corresponding normalized intensity profiles along the dash white line for *x*-polarized incidence. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

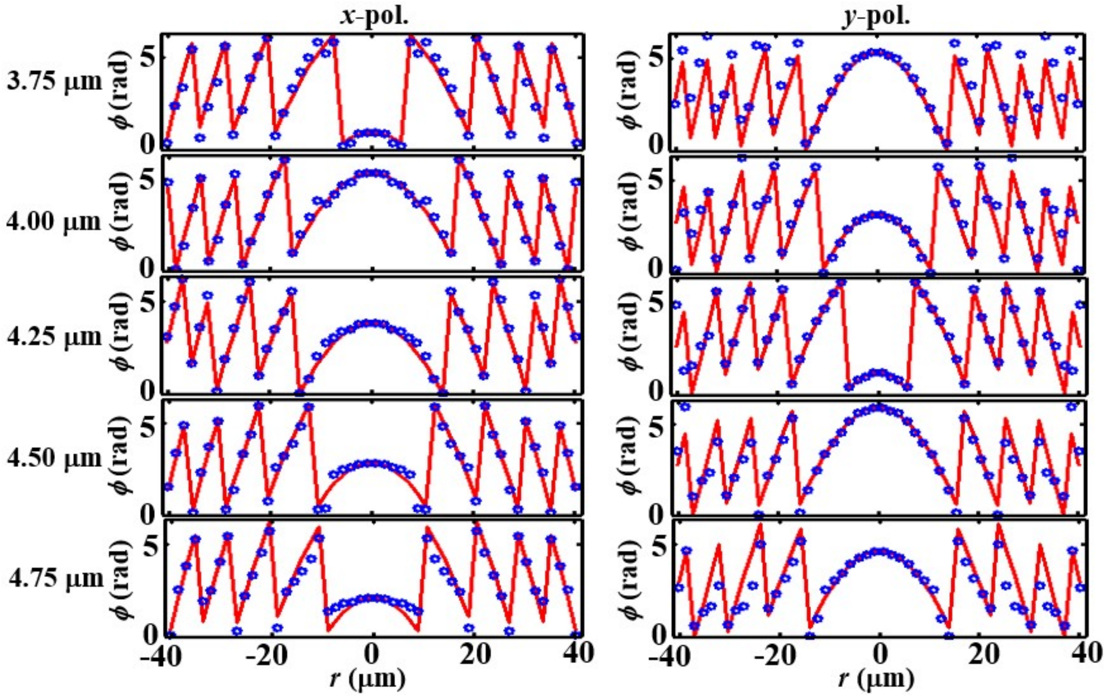

Fig. S4. The required and achieved phase profiles for the designed BACDPSM1. Left panel is hyper-dispersive for *x*-polarization and right panel is achromatic for *y*-polarization.

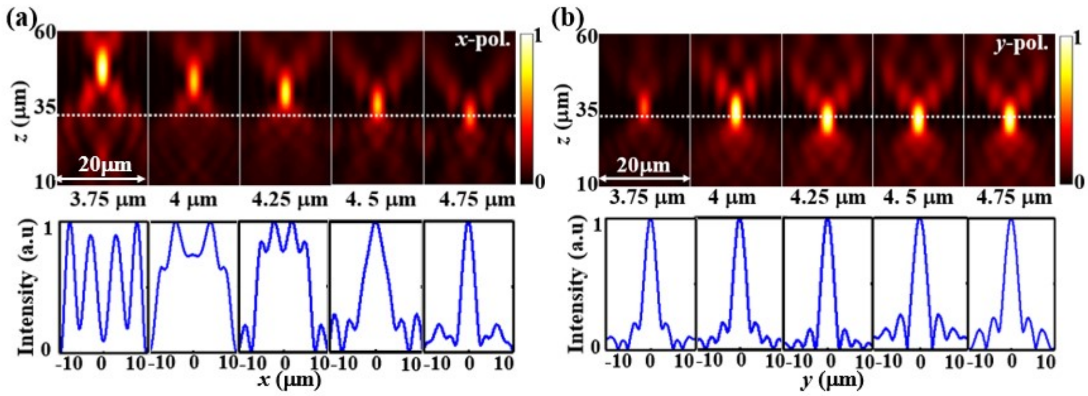

Fig. S5. Simulated results of the designed BACDPSM1. The BACDPSM1 is designed at a basic wavelength λ=4.75 μm with focal length f=30 μm. (a) Hyper- dispersion for the *x*-polarization and (b) achromatic for *y*-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line for *x*-polarized incidence. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

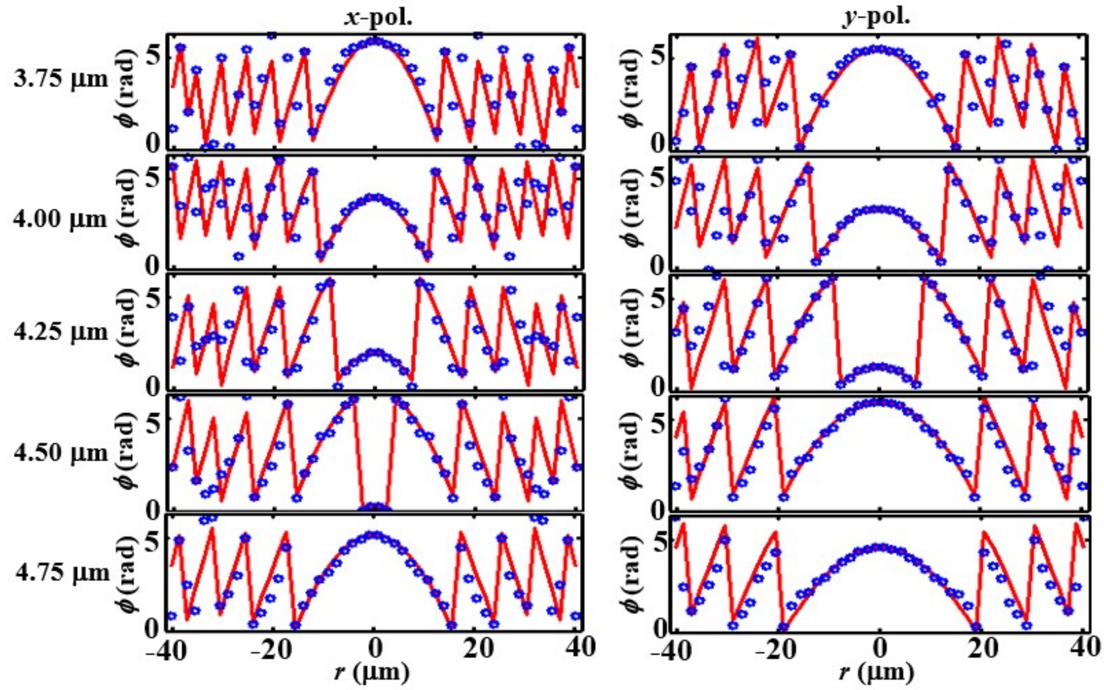

Fig. S6. The required and achieved phase profiles for the designed BACDPSM2. Left panel and right panel are positive dispersive for *x*-polarization and *y*-polarization, respectively. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

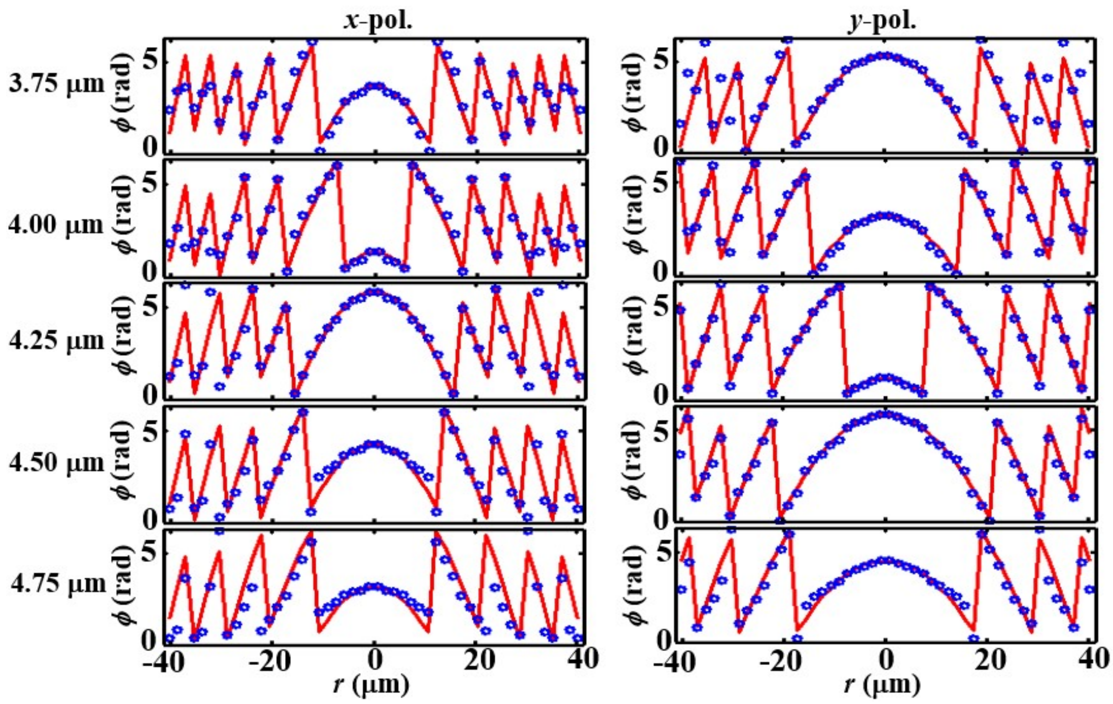

Fig. S7. The required and achieved phase profiles for the designed BACDPSM3. Left panel and right panel are achromatic for *x*-polarization and *y*-polarization, respectively.

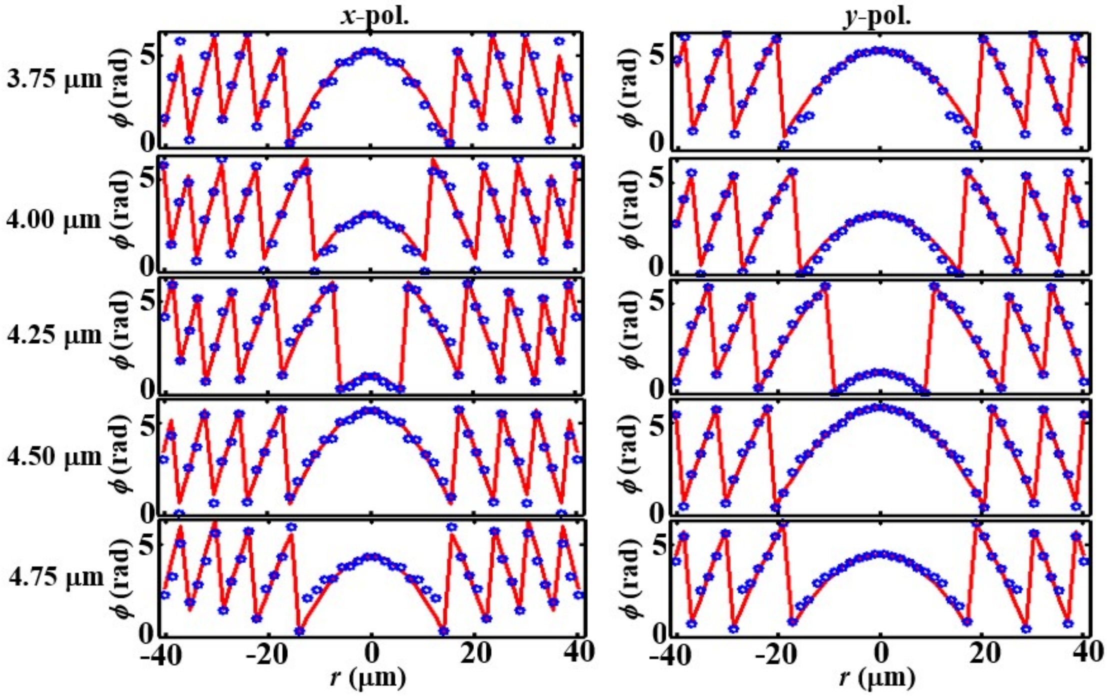

Fig. S8. The required and achieved phase profiles for the designed BACDPSM4. Left panel and right panel are regular (negative) dispersive for *x*-polarization and *y*-polarization, respectively. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

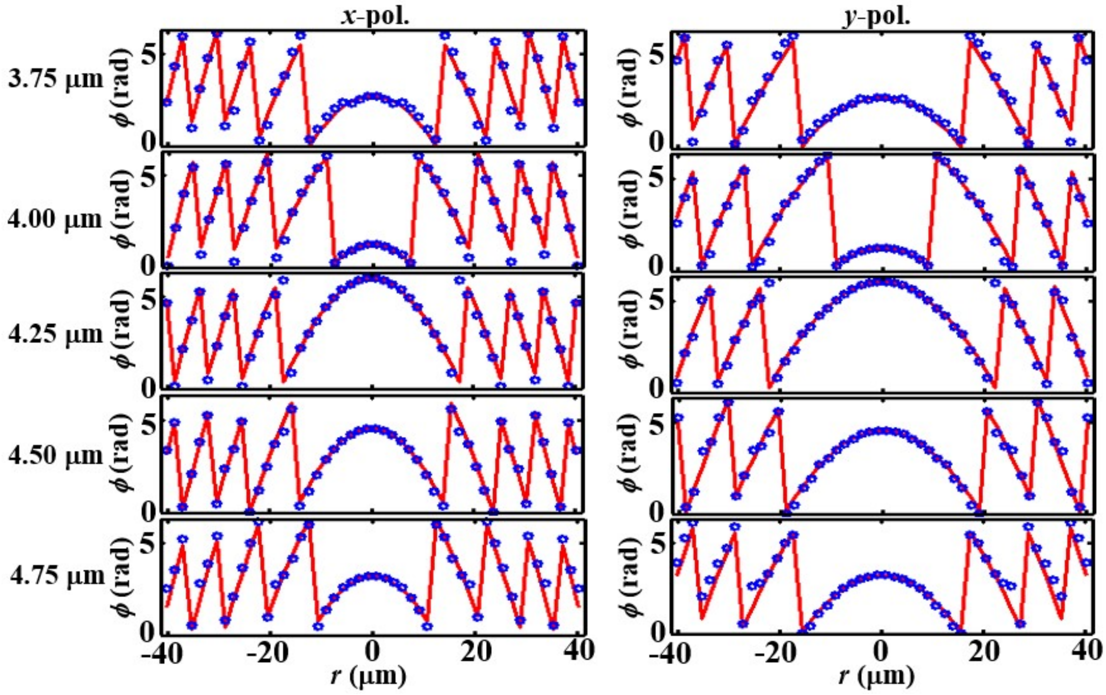

Fig. S9. The required and achieved phase profiles for the designed BACDPSM5. Left panel and right panel are hyper- dispersive for *x*-polarization and *y*-polarization, respectively.

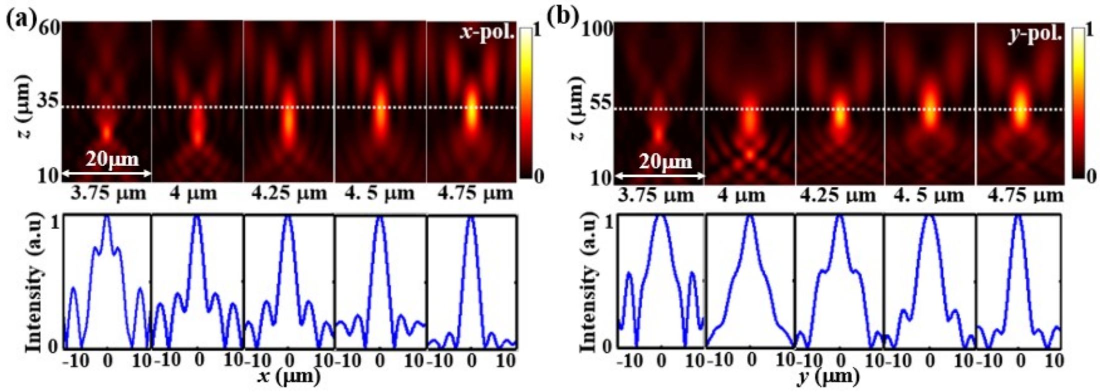

Fig. S10. Simulated results of the designed BACDPSM2. The BACDPSM2 is positive dispersion and designed at a basic wavelength λ=4.75 μm with (a) focal length f_x=30 μm for the *x*-polarization and (b) f_y=50 μm for the *y*-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

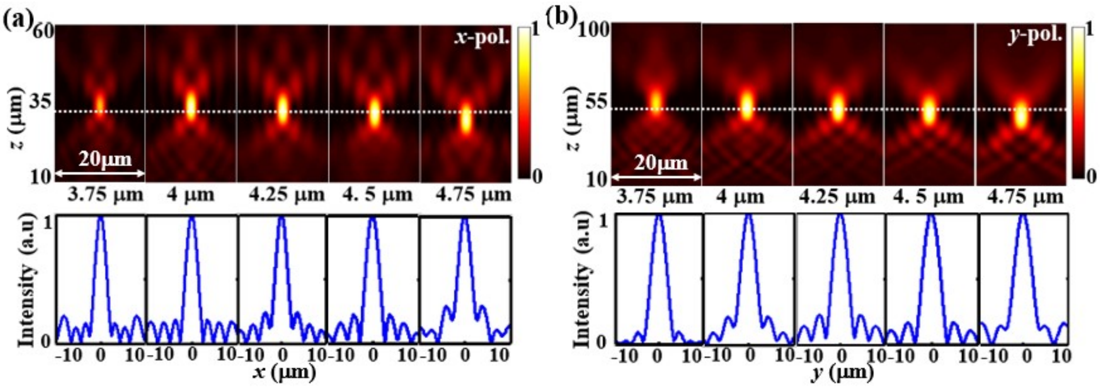

Fig. S11. Simulated results of the designed BACDPSM3. The BACDPSM3 is achromatic and designed at a basic wavelength λ=4.75 μm with (a) focal length f_x=30 μm for the *x*-polarization and (b) f_y=50 μm for the *y*-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

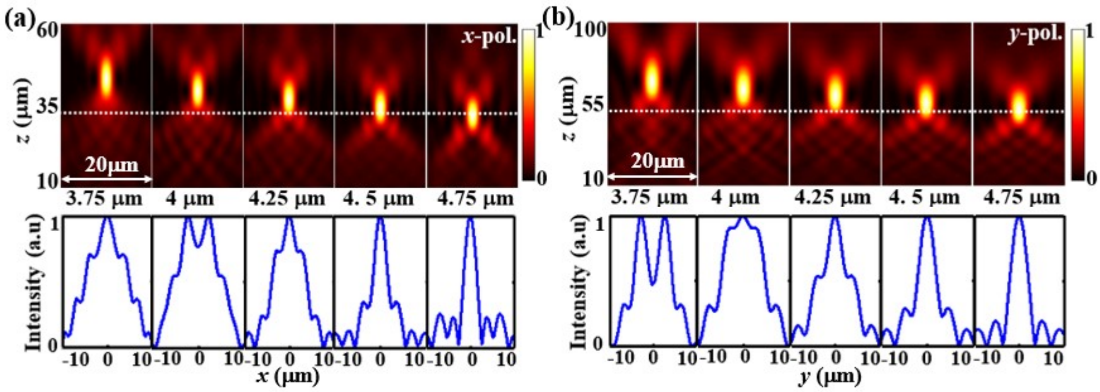

Fig. S12. Simulated results of the designed BACDPSM4. The BACDPSM4 is regular (negative) dispersion and designed at a basic wavelength λ=4.75 μm with (a) focal length f_x=30 μm for the *x*-polarization and (b) f_y=50 μm for the *y*-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

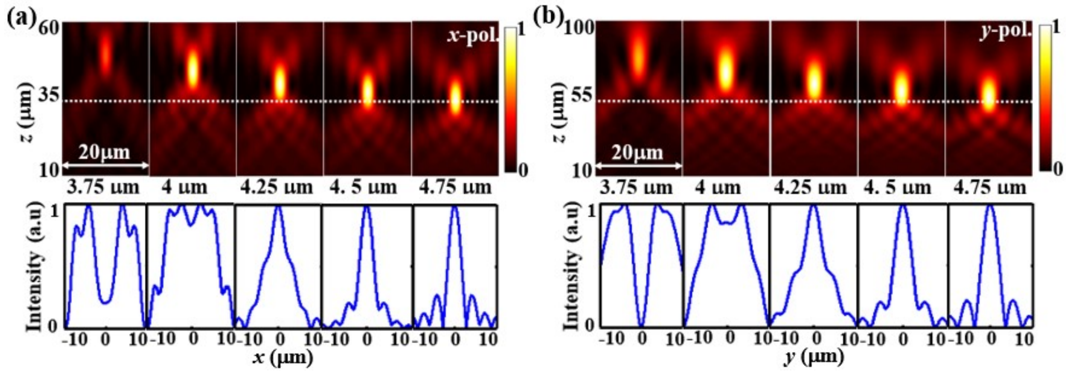

Fig. S13. Simulated results of the designed BACDPSM5. The BACDPSM5 is hyper- dispersion and designed at a basic wavelength λ=4.75 μm with (a) focal length f_x=30 μm for the x-polarization and (b) f_y=50 μm for the y-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

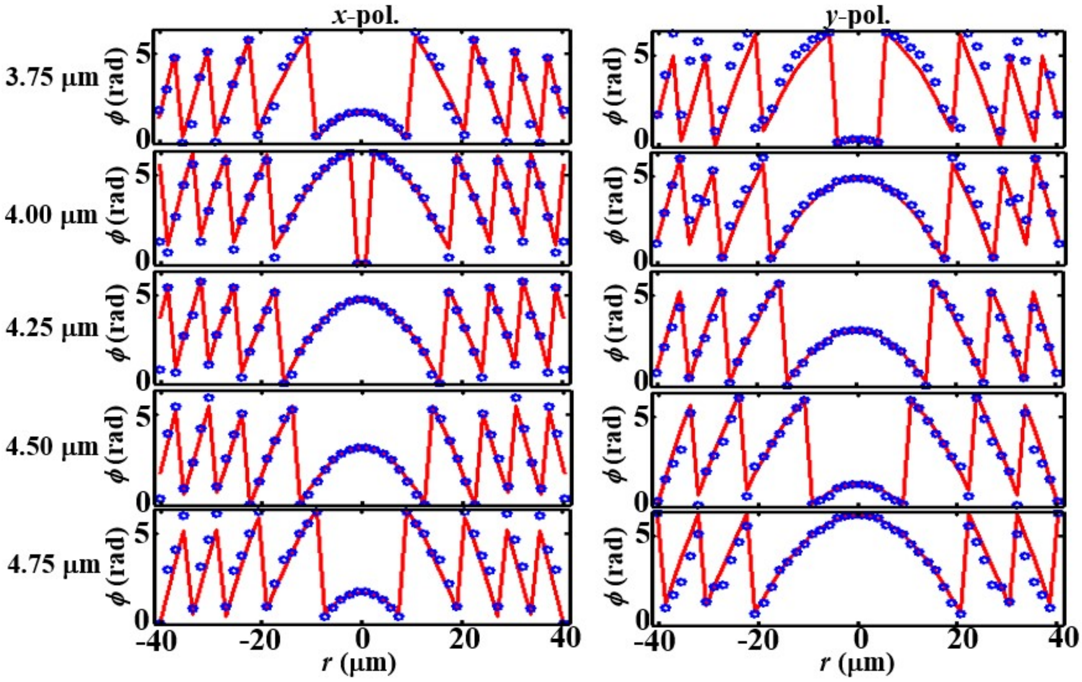

Fig. S14. The required and achieved phase profiles for the designed BACDPSM6. Left panel is hyper-dispersive for x-polarization and right panel is achromatic for y-polarization.

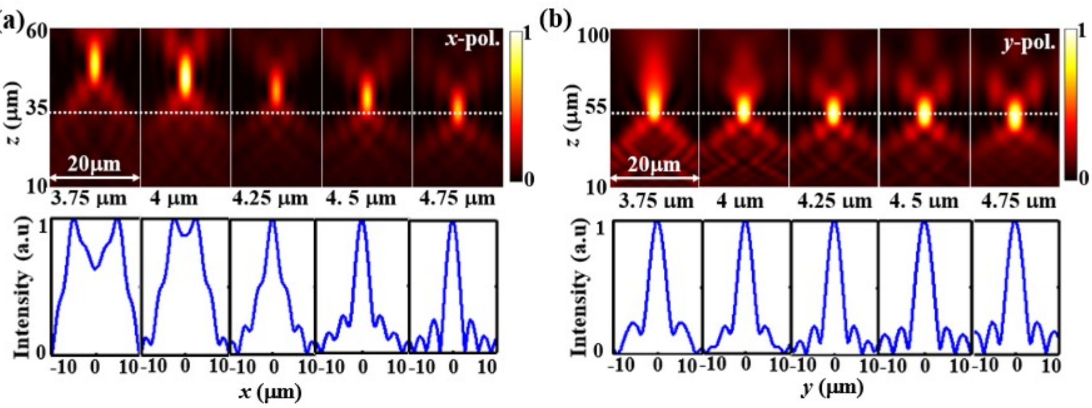

Fig. S15. Simulated results of the designed BACDPSM6. The BACDPSM6 is designed at a basic wavelength λ=4.75 μm with (a) focal length f_x=30 μm, hyper- dispersion for the x-polarization and (b) focal length f_y=50 μm, achromatic for y-polarization. The top panel is the intensity profiles and the bottom panel is the corresponding normalized intensity profiles along the dash white line. Only five wavelength are shown here, but the dispersions are valid for any other wavelength in the bandwidth of 3.75-4.75 μm.

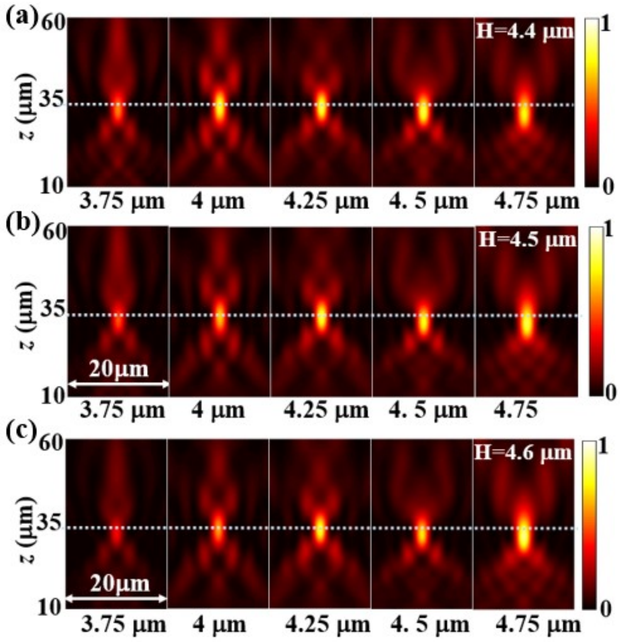

Fig. S16. The numerical intensity profiles of the broadband polarization-insensitive achromatic metalens with different fabrication error on height deviations. (a) H=4.4 μm, (b) H=4.5 μm, and (c) H=4.6 μm.

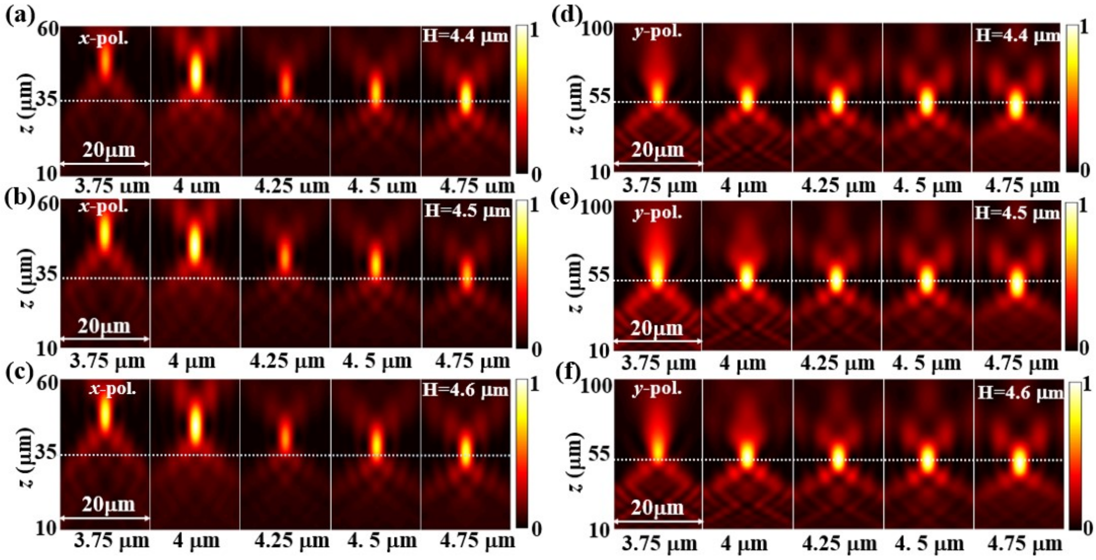

Fig. S17. The numerical intensity profiles of the BACDPSM6 with different fabrication error on height deviations for *x*-polarization and *y*-polarization. (a),(d) H=4.4 μm, (b) ,(e) H=4.5 μm, and (c) ,(f) H=4.6 μm.

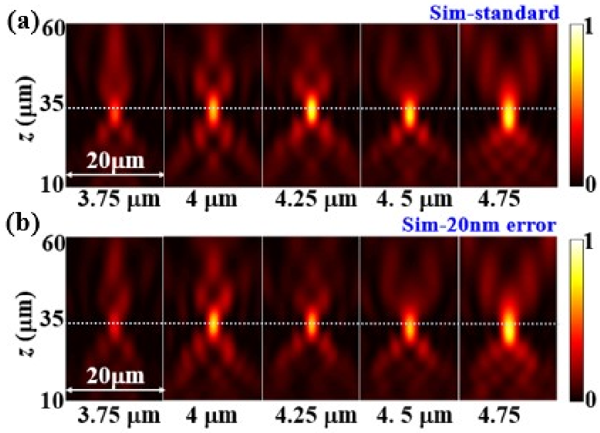

Fig. S18. The numerical intensity profiles of the broadband polarization-insensitive achromatic metalens with different fabrication error on 20 nm shape deviations. (a) Actual designed structures. (b) Structures with 20 nm error of the semi-major axis and semi-minor axis.

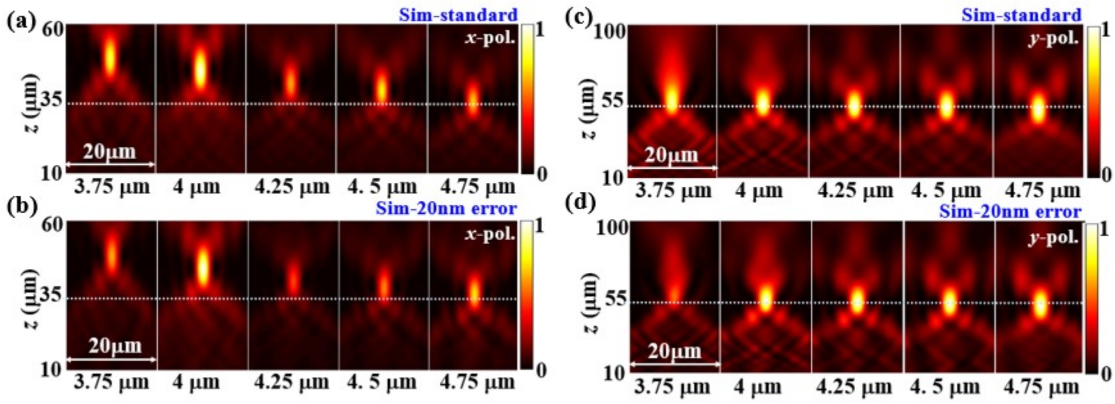

Fig. S19. The numerical intensity profiles of the BACDPSM6 with different fabrication error on 20 nm shape deviations for x-polarization and y-polarization. (a),(c) Actual designed structures. (b),(d) Structures with 20 nm error of the semi-major axis and semi-minor axis.

The total number of meta-atoms along the diameter of the designed metalenses is 50. We only show half the number of meta-atoms because the arrangements of meta-atoms of the designed metalenses are symmetric along the central of diameter.

Table S1. Parameters of the selected meta-atoms for the designed positive dispersion BACDPIM.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	510	510
2	500	510
3	500	490
4	300	600
5	700	700
6	670	670
7	620	610
8	400	400
9	360	360
10	220	220
11	470	470
12	460	470

13	440	380
14	310	320
15	200	200
16	510	520
17	500	500
18	330	340
19	610	620
20	460	470
21	520	530
22	380	380
23	690	690
24	510	510
25	290	610

Table S2. Parameters of the selected meta-atoms for the designed achromatic BACDPIM.

Unit element	Semi-minor axis a (nm)	Semi-major axis b (nm)
1	490	510
2	490	500
3	480	500
4	460	490
5	460	470
6	440	460
7	610	650
8	610	610
9	520	590
10	520	520
11	630	630
12	670	670
13	410	430
14	360	380
15	220	220
16	680	690
17	390	420
18	360	360
19	200	270
20	630	430
21	430	440
22	300	320
23	470	470
24	430	440
25	530	520

Table S3. Parameters of the selected meta-atoms for the designed negative dispersion BACDPIM.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	490	500
2	490	490
3	480	490
4	470	480
5	460	470
6	450	450
7	630	630
8	570	620
9	560	560
10	520	540
11	490	500
12	460	470
13	640	660
14	570	590
15	520	540
16	480	500
17	450	450
18	630	630
19	530	530
20	600	600
21	650	670
22	400	400
23	520	520
24	700	700
25	420	420

Table S4. Parameters of the selected meta-atoms for the designed hyper-dispersive BACDPIM.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	700	700
2	690	700
3	680	680
4	660	660
5	640	640
6	610	620
7	590	580
8	560	560
9	530	530
10	500	500
11	300	600
12	660	660
13	600	610
14	560	560

15	520	520
16	490	480
17	450	450
18	580	590
19	540	530
20	490	490
21	450	450
22	580	580
23	530	530
24	480	480
25	630	630

Table S5. Parameters of the selected meta-atoms for the designed BACDPSM1.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	370	590
2	370	580
3	360	580
4	360	560
5	350	540
6	340	520
7	610	390
8	440	700
9	430	640
10	420	580
11	400	540
12	700	400
13	650	370
14	620	330
15	440	560
16	620	700
17	540	670
18	700	310
19	700	240
20	640	690
21	420	390
22	700	300
23	700	230
24	400	570
25	690	380

Table S6. Parameters of the selected meta-atoms for the designed BACDPSM2.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	540	500
2	530	500
3	520	500
4	510	500
5	480	490
6	460	490
7	660	480
8	400	700
9	360	470
10	210	450
11	630	560
12	650	320
13	350	200
14	290	590
15	200	600
16	650	660
17	550	330
18	540	300
19	310	220
20	630	670
21	660	430
22	340	380
23	490	430
24	590	330
25	620	390

Table S7. Parameters of the selected meta-atoms for the designed BACDPSM3.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	440	540
2	430	540
3	430	540
4	420	530
5	400	530
6	390	530
7	370	510
8	620	510
9	570	400
10	540	400
11	380	380
12	350	700
13	310	690
14	250	680

15	700	700
16	410	690
17	340	440
18	290	430
19	200	390
20	460	220
21	280	480
22	230	520
23	630	510
24	260	270
25	200	700

Table S8. Parameters of the selected meta-atoms for the designed BACDPSM4.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	500	510
2	490	510
3	480	510
4	480	510
5	450	500
6	450	500
7	420	490
8	400	490
9	530	480
10	500	700
11	450	700
12	420	680
13	390	640
14	690	620
15	590	450
16	530	450
17	470	430
18	650	430
19	540	550
20	490	540
21	440	510
22	390	480
23	480	460
24	430	650
25	390	590

Table S9. Parameters of the selected meta-atoms for the designed BACDPSM5.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	700	700
2	690	700
3	670	700
4	640	700
5	620	700
6	590	680
7	550	670
8	530	660
9	500	640
10	470	620
11	450	620
12	410	580
13	700	580
14	630	440
15	580	440
16	510	420
17	700	420
18	630	550
19	550	520
20	490	500
21	450	490
22	560	460
23	510	660
24	450	580
25	410	570

Table S10. Parameters of the selected meta-atoms for the designed BACDPSM6.

Unit element	Semi-minor axis *a* (nm)	Semi-major axis *b* (nm)
1	700	510
2	690	510
3	670	510
4	650	500
5	620	500
6	590	500
7	560	490
8	540	480
9	500	470
10	490	450
11	650	640
12	590	620
13	540	610
14	510	550

15	470	530
16	440	500
17	560	700
18	700	350
19	650	310
20	430	570
21	700	430
22	670	370
23	580	350
24	550	300
25	230	200