The optical vortices structure controlling by changing the height of silicon ring gratings using high-performance computer systems

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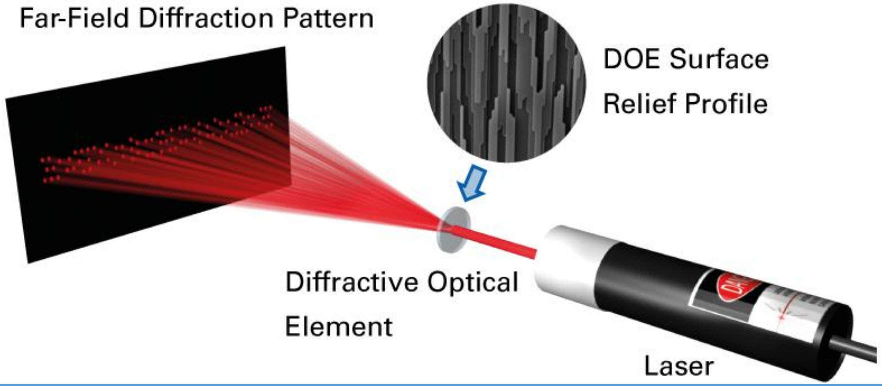
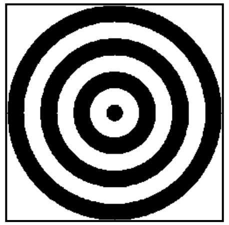
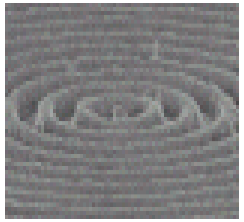


- **DOE is designed to form the required distribution** of the electromagnetic field.
- **The main difficulty** in the synthesis of DOEs is the **solution of the inverse diffraction problem**.
- **Examples**: Fresnel lens, diffraction gratings, interference holograms, synthesized diffraction relief, metasurfaces, depicting and non-depicting DOE.

Diffractive axicon:

Structure of the element

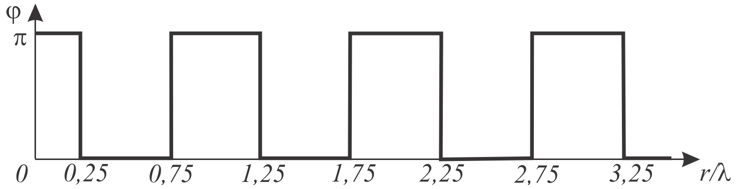




The complex transmission function

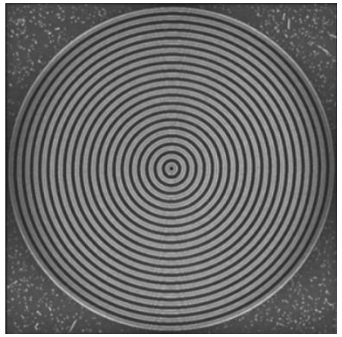
$$\tau_b(r) = \begin{cases} \exp\{i\arg[\cos(k\alpha_0 r)]\}, & r \le R, \\ 0, & r > R. \end{cases}$$

The radial cross section of the phase element

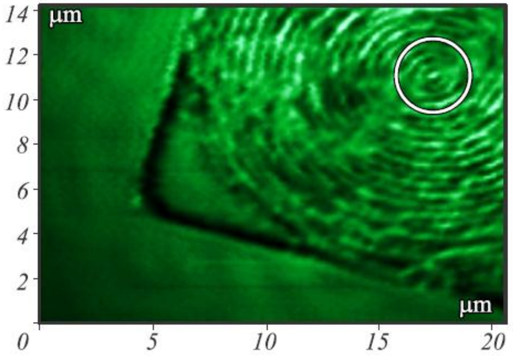


Experimental demonstration on the optical axis with high-numerical-aperture binary axicons illuminated by linearly and circularly polarized beams:

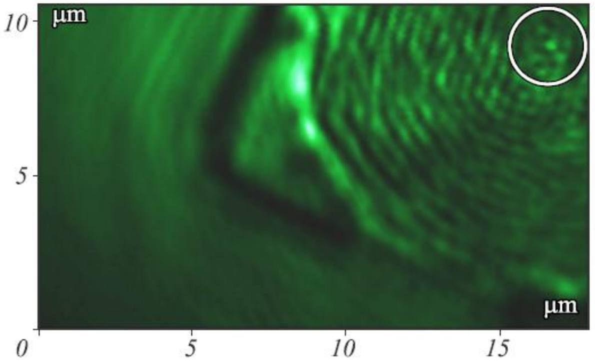
SEM image of axisymmetric binary axicon



linearly polarized beam



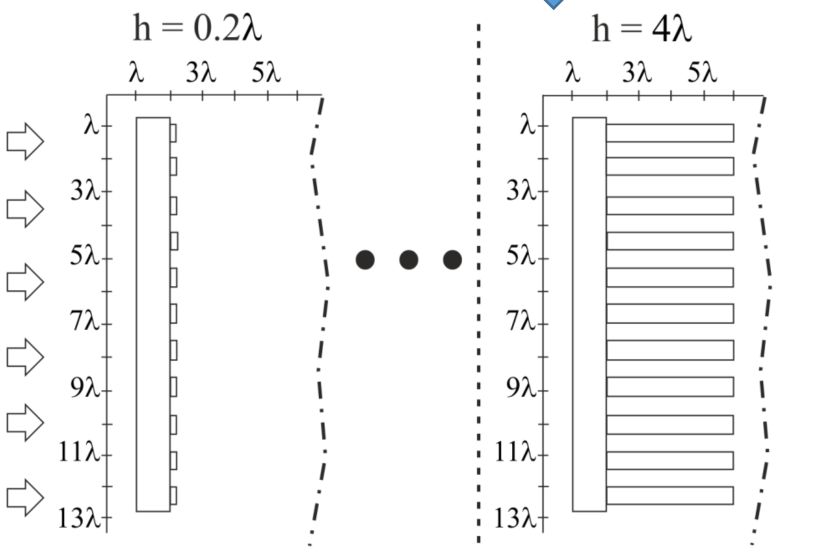
circularly polarized beam



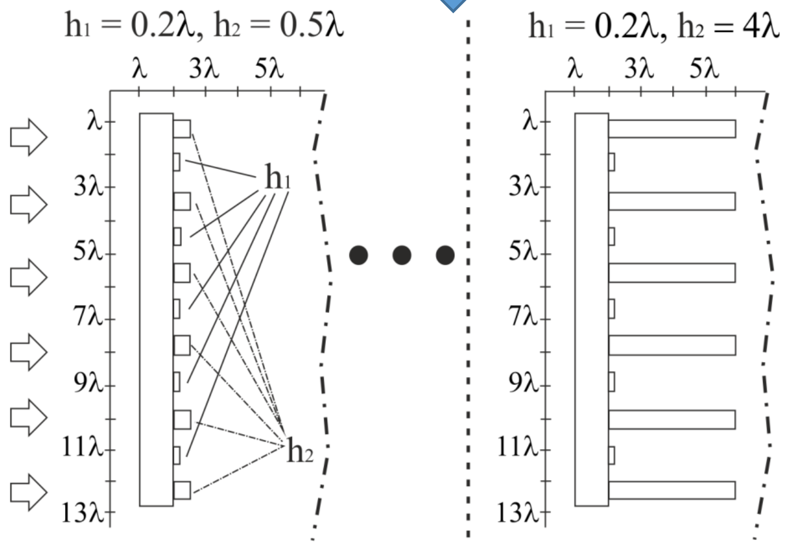
Khonina, S. N., Karpeev, S. V., Alferov, S. V., **Savelyev, D. A.**, Laukkanen, J., & Turunen, J. (2013). Experimental demonstration of the generation of the longitudinal E-field component on the optical axis with high-numerical-aperture binary axicons illuminated by linearly and circularly polarized beams. ***Journal of Optics***, *15*(8), 085704.

RING GRATINGS AND INPUT BEAMS

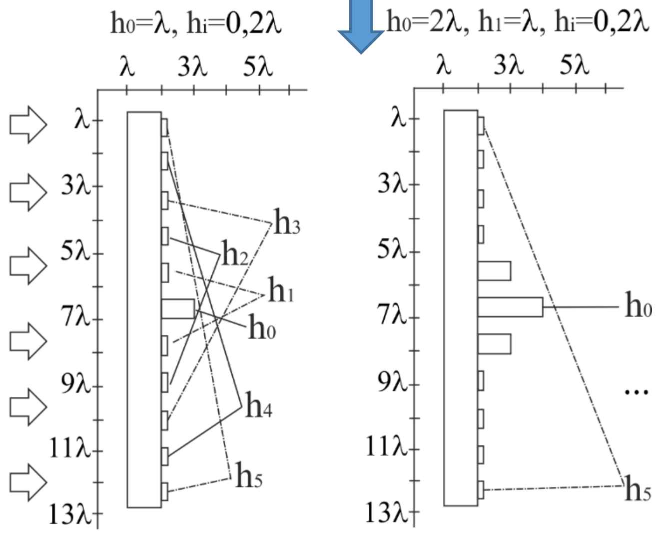
Ring Gratings

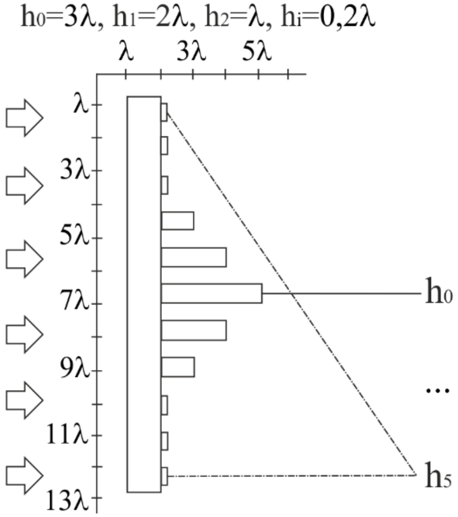


The examples of profiles of the considered **silicon axicons** with minimum and maximum heights (from 0.2λ to 4λ)



The examples of profiles of the considered **silicon ring gratings** with minimum and maximum heights h_2



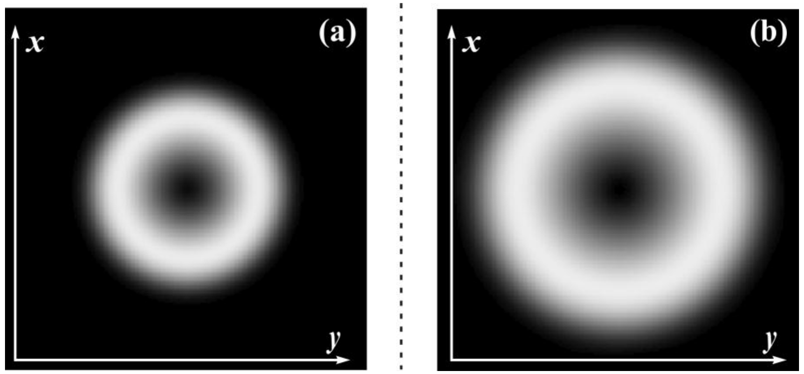


The examples of profiles of considered **silicon ring gratings** with **different** height h_i

The input beams:

(a) σ = 5 μm and (b) σ = 7.3 μm

$$A(r,\varphi) = r \cdot \exp\left[-\frac{r^p}{2\sigma^p}\right] \cdot e^{i\varphi},\ p = 6.$$



SIMULATION PARAMETERS

- **The wavelength** λ = 1.55 μm.
- **The size** of the computational domain x, y, z in [–5.7λ; 5.7λ].
- **The thickness** of the **absorbing layer** PML ~ λ,
- **The sampling step** of space – λ/30, the sampling step of time – λ/(60c), where c is the light velocity.
- The Laguerre-Gauss mode (1,0) (**optical vortex**) with different beam width was considered as **input laser beams**.
- **Circular polarization** (the *sign* of circular polarization *is opposite* to the *sign* of the *introduced vortex phase singularity*).
- **The numerical aperture** (NA) of the focusing binary axicon was **0.95** (*grating period 1,05λ*).
- **The refractive index** of the optical element is **n = 3.47**.
- **The height of the relief** of the annular grating **changed from 0.2λ to 4λ**.
- **Diffraction modeling (3D)** was performed using the **finite difference time domain (FDTD)** method.
- **For calculations** used a free-software package **Meep**.
- **The calculations** were carried out on **computing cluster** with a 950 GFlop power.

CLUSTER "SERGEY KOROLEV"

General characteristics:

- The total number of processors / cores: 360/1992;
- Total number of graphics processors / cores: 5/4216;
- Total Memory: 6672 GB;
- System network: QLogic / Voltaire InfiniBand DDR, QDR;
- Type of control support network: Gigabit Ethernet;
- Operating system: Red Hat Enterprise Linux.

The computing part includes:

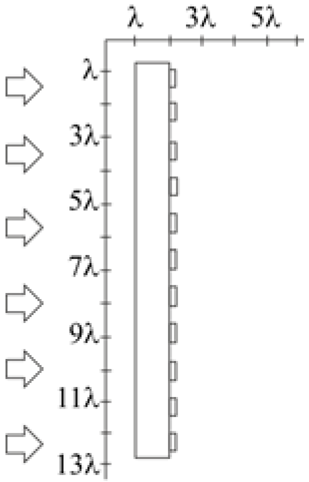
- 112 BladeCenter HS22 blade server computing with 2x Intel Xeon X5560;
- 28 HS23 blade servers with 2x Intel Xeon E5-2665;
- 14 HS23 blade servers with 2x Intel Xeon E5-2680v2;
- 14 HS22 blade servers with 24 GB of memory on the server with 2x Intel Xeon X5670;
- 8 HS22 blade servers with 96 GB memory on the server with 2x Intel Xeon X5670;
- 2 HS22 blade servers with graphics cards Nvidia Tesla 2070;
- SMP server, CPU – 4x Intel Xeon E7-4860, GPGPU – Nvidia Tesla K20c.
- Etc…

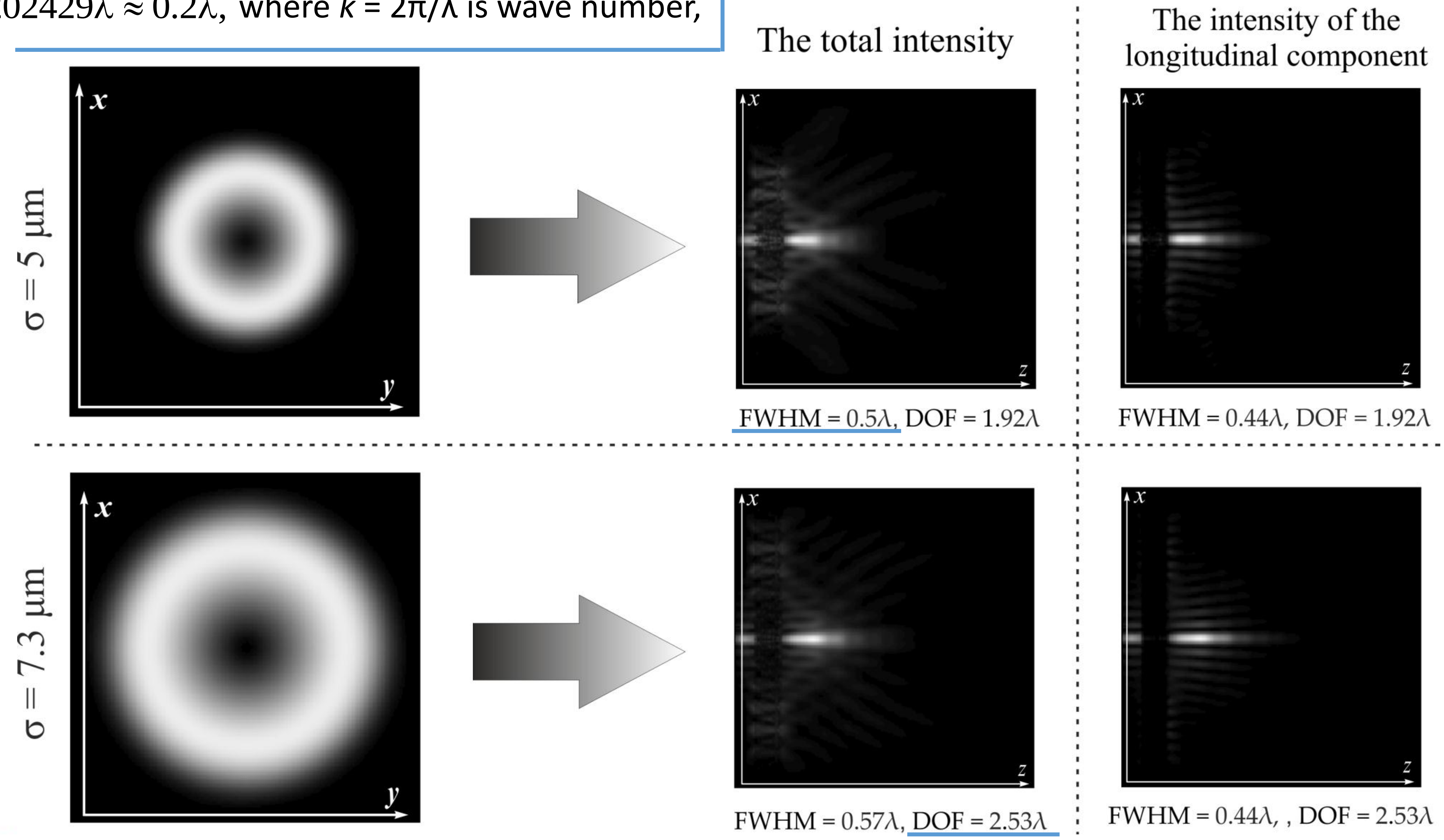
LASER RADIATION PROPAGATION THROUGH SILICON AXICONS FROM h = 0.2λ

$h = \dfrac{\pi}{k(n-1)} = 0.202429\lambda \approx 0.2\lambda$, where $k = 2\pi/\lambda$ is wave number,

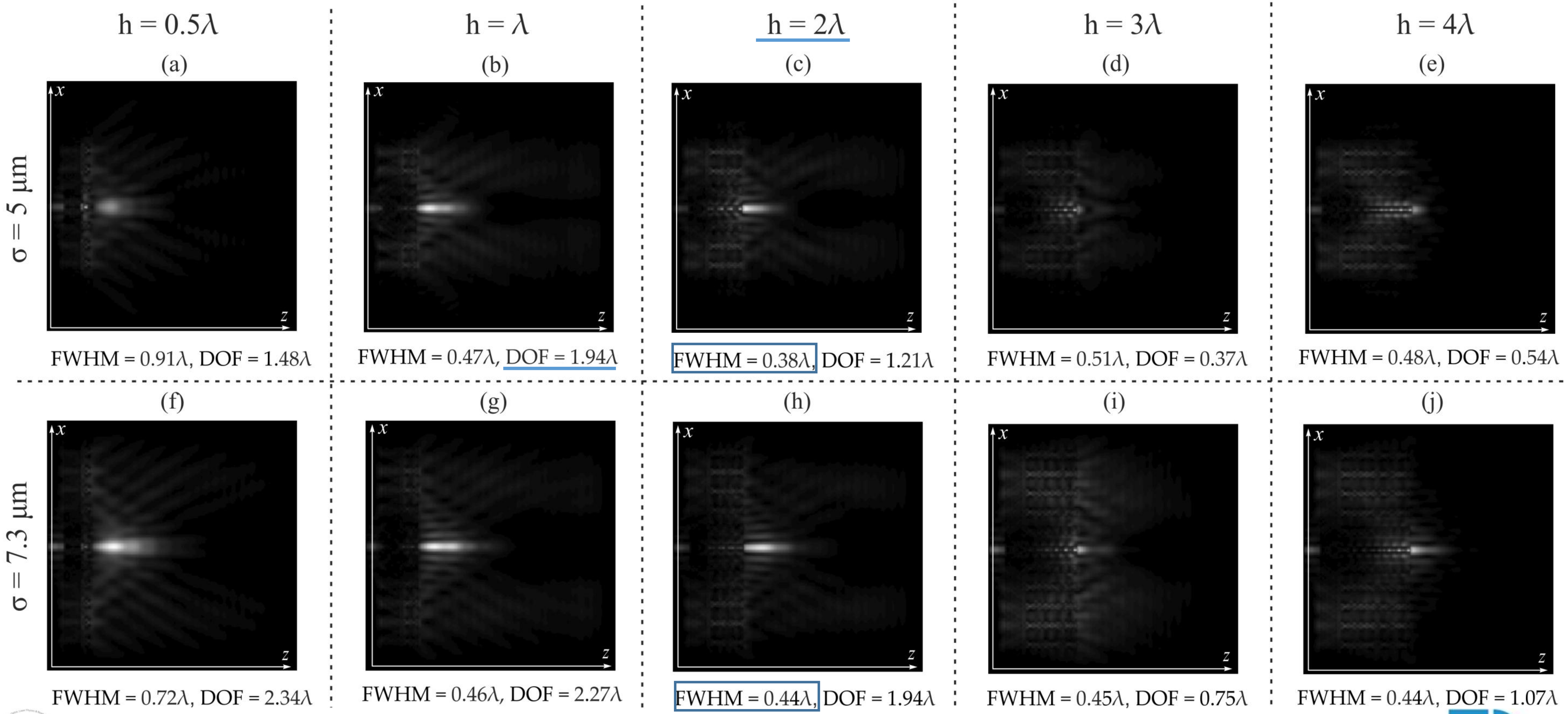
λ is wavelength of laser radiation, and *n* is refractive index.

The relief height corresponded to the phase jump π radians.

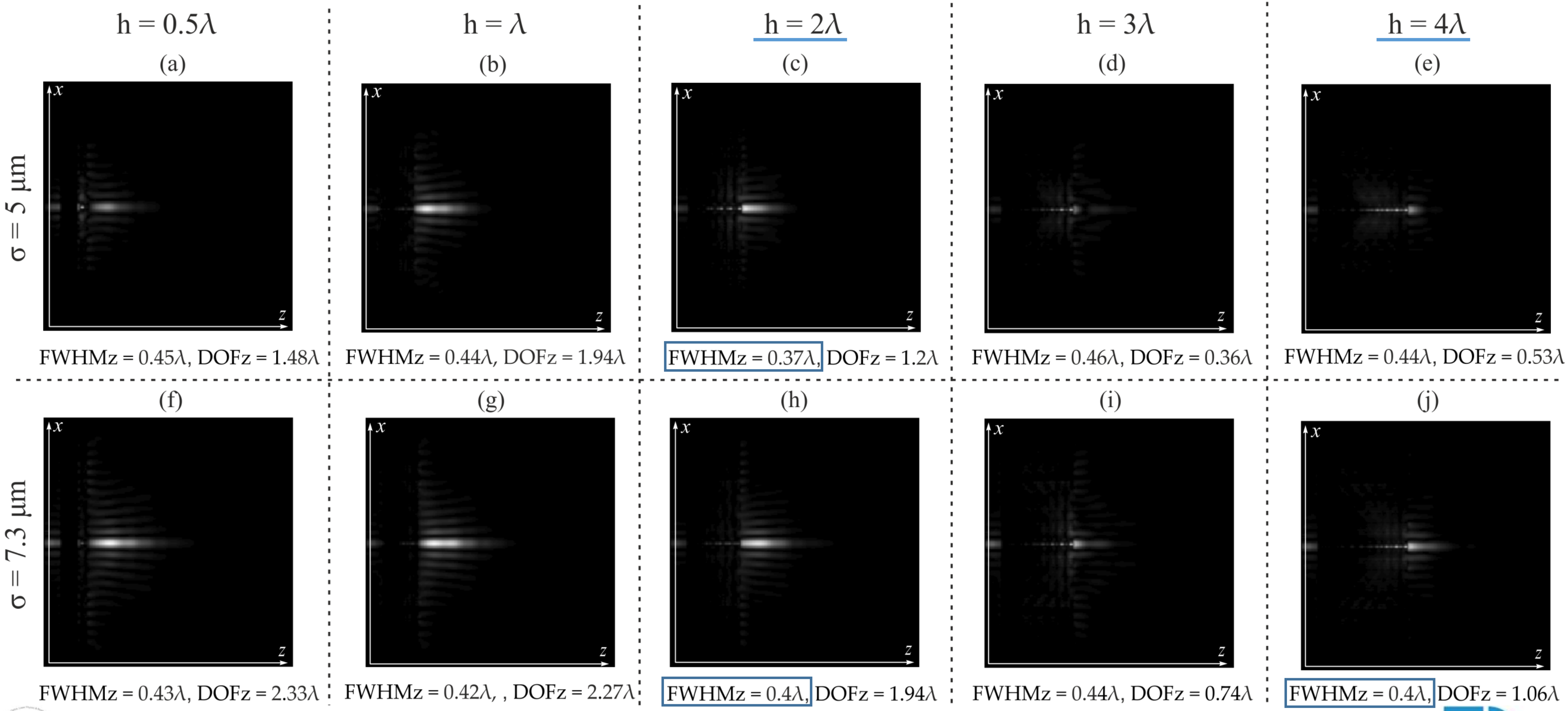




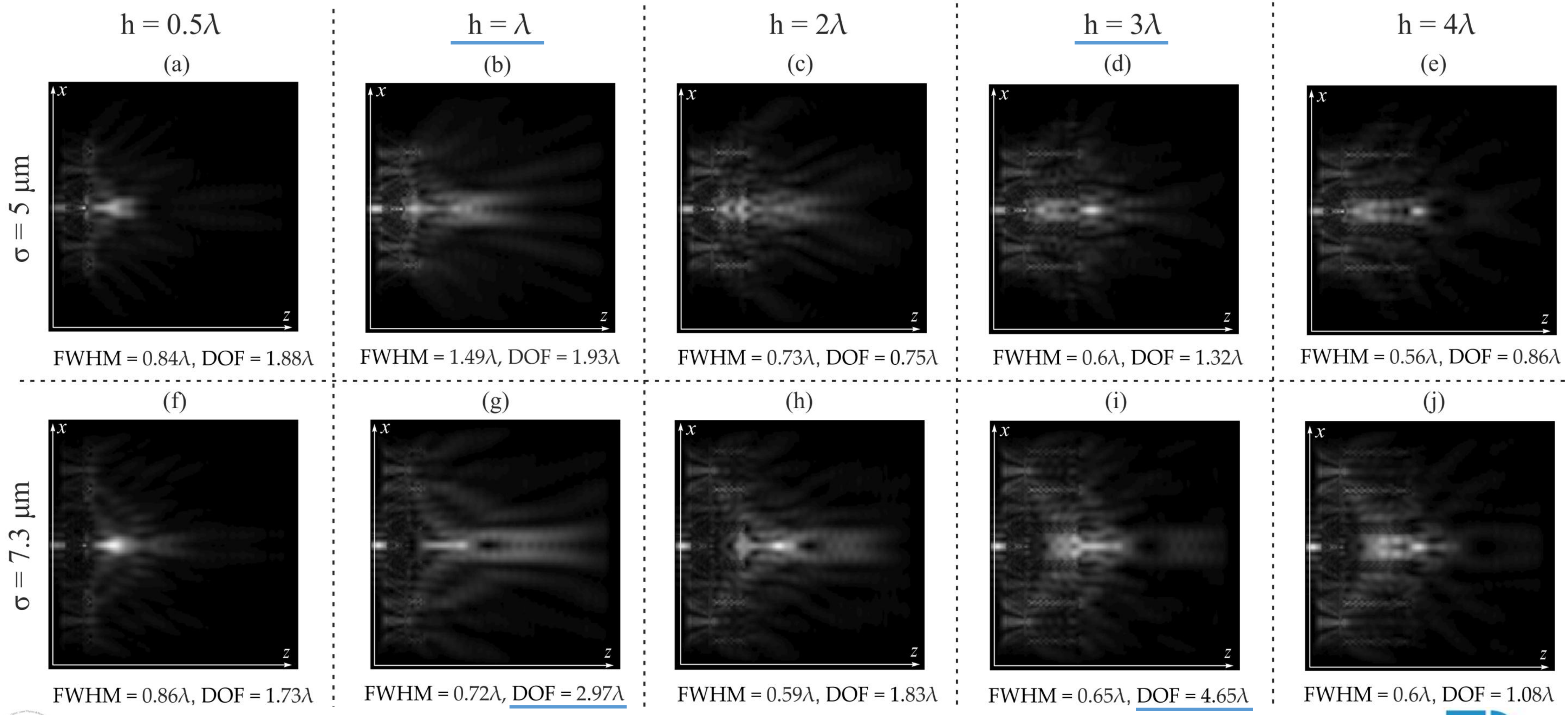
LASER RADIATION PROPAGATION THROUGH SILICON AXICONS FROM h = 0.5λ TO h = 4λ, TOTAL INTENSITY



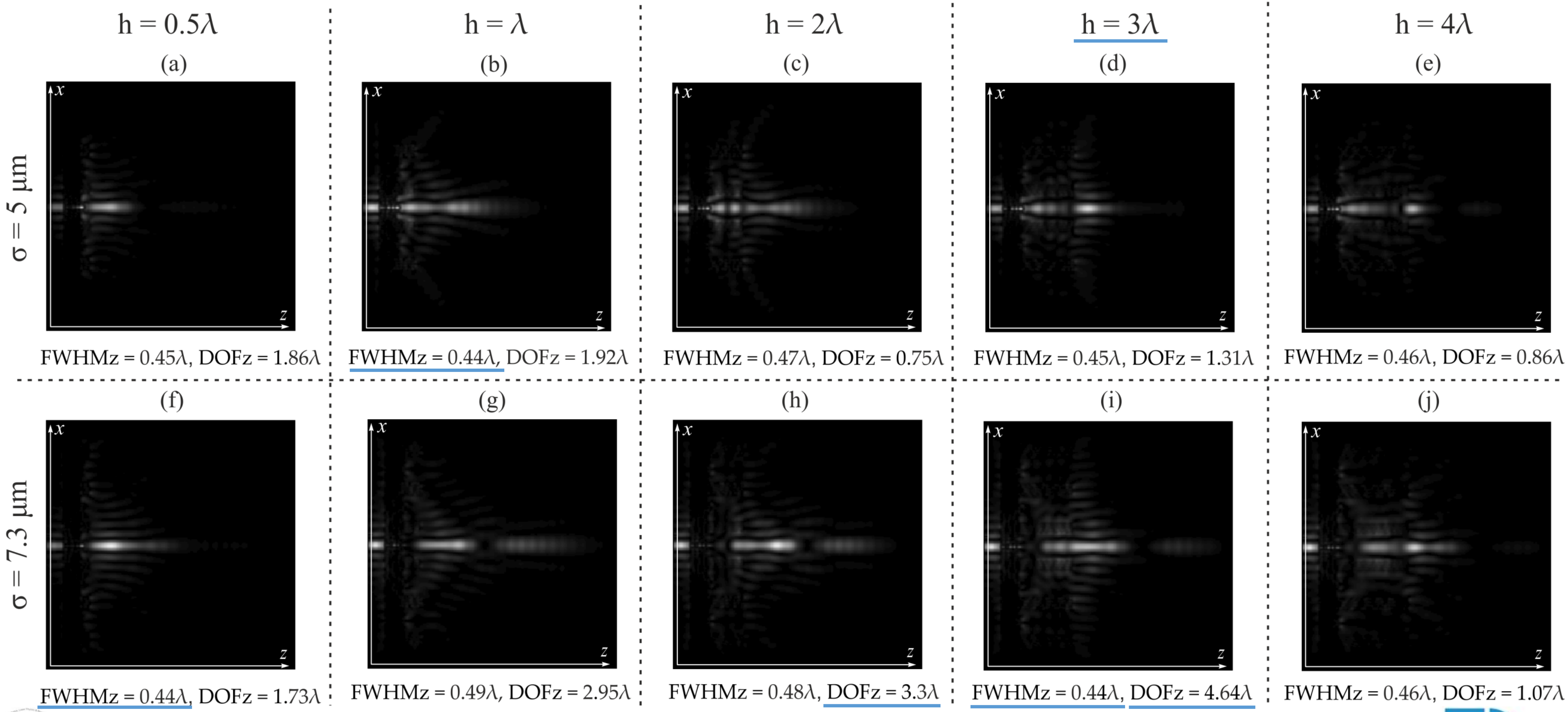
LASER RADIATION PROPAGATION THROUGH SILICON AXICONS FROM h = 0,5λ TO h = 4λ, INTENSITY OF THE LONGITUDINAL COMPONENT



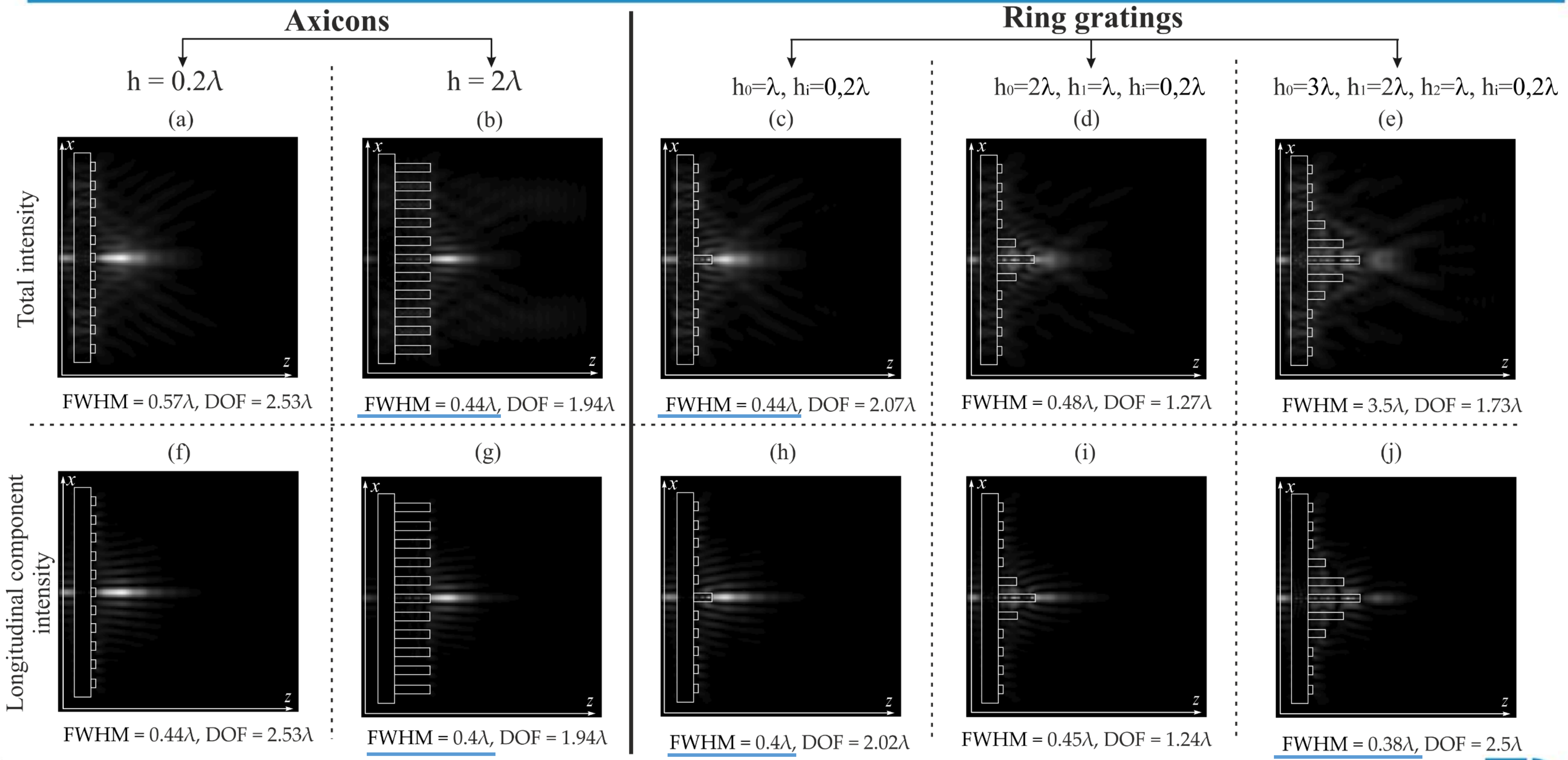
LASER RADIATION PROPAGATION THROUGH SILICON RING GRATINGS FROM h = 0,5λ TO h = 4λ, TOTAL INTENSITY



LASER RADIATION PROPAGATION THROUGH SILICON RING GRATINGS FROM h = 0,5λ TO h = 4λ, INTENSITY OF THE LONGITUDINAL COMPONENT



LASER RADIATION PROPAGATION ON RING GRATINGS WITH VARIABLE RELIEF HEIGHT, σ = 7.3 μm



Conclusions:

- The diffraction of **optical vortices with circular polarization** with different widths on **silicon ring gratings and diffractive axicons** by the finite difference time domain method were simulated.
- **The heights** of individual grating rings **were varied**.
- **The smallest focal spot size was obtained for a silicon diffractive axicon at a relief height h = 2λ for a laser beam with σ = 5 μm** (FWHM = 0.38λ, FWHMz = 0.37λ), which *is better than the action of a diffractive axicon with a height h = 0.2λ* (FWHM = 0.5λ, FWHMz = 0.44λ) *by 24%.*
- The results of numerical simulation for ring gratings **with different heights h_i** (increase in center height from λ to 3 λ) showed that, in the general case, an **increase in height leads to the formation of a maximum inside the element**.
- **The largest light needle length** was obtained for silicon ring gratings (laser beam width **σ = 7.3 μm**) **at a height h_2 = 3λ and h_1 = 0.2λ (DOF = 4.65λ)**, which is ***83.8% longer*** than the light needle of a diffractive axicon with a height h = 0.2λ.

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