Artificial wave plates made from sub-wavelength structures

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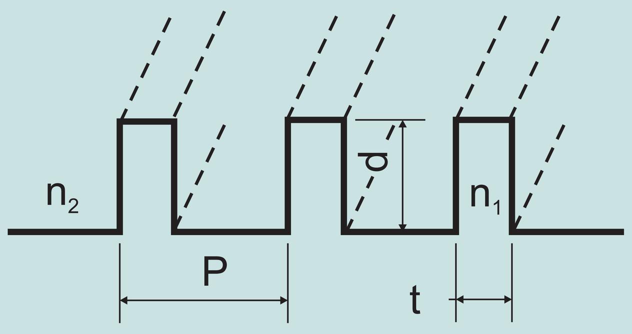
Optical Design and Measuremen

Motivation

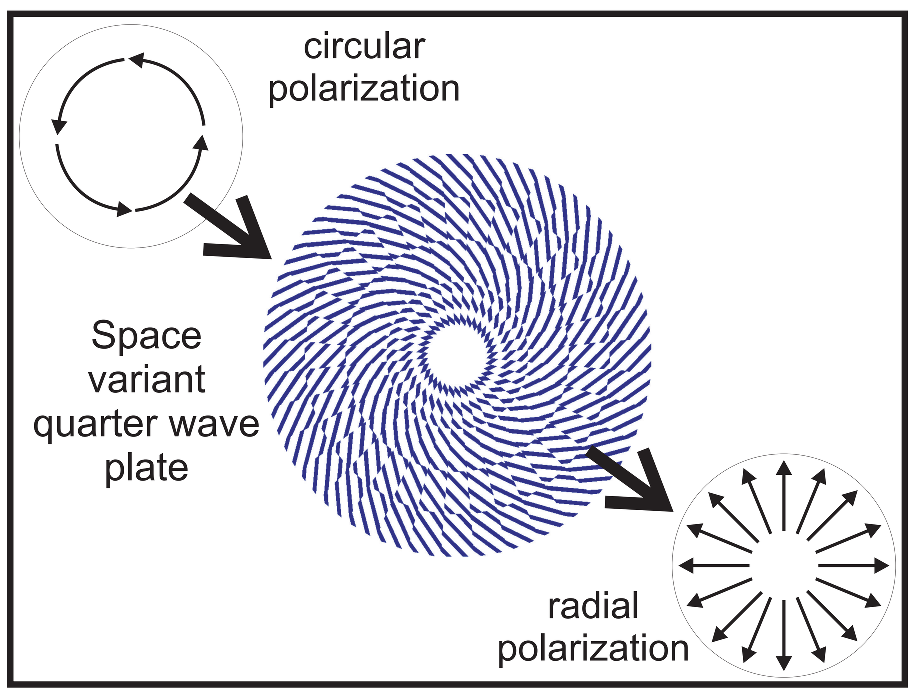
Aim: Generation of radially polarized light (λ=633nm) with polarization elements made from Si3N4 sub-λ gratings

The form birefringence of a dielectric material is achieved by structuring the surface in the nano meter range.
Two different designs (phase retardation Δ of π/2 respectively π) are presented.
The structure is a binary sub-λ grating, whose geometry parameters are calculated with the effective medium theory:

$$n_{\parallel} \quad \sqrt{\frac{t}{P} n \quad (\quad \frac{t}{P}) n} \qquad n \quad \frac{n\, n}{\sqrt{\frac{t}{P} n \quad (\quad \frac{t}{P}) n}} \qquad — d(n_{\parallel} \quad n \;)$$



Design



general grating vector of a space variant sub-wavelength structures :

$\vec{K}_G = K_0(r;\theta)(\cos\beta(r;\theta)\,\hat{r} + \sin\beta(r;\theta)\,\hat{\theta})$ with β(r;θ): angle between grating vector and x axis

The continuity of the grating requires: $\nabla \times \vec{K}_G = 0$

Space variant quarter wave plate [1]:

$K_0(r) = \frac{2\pi\, r_0}{P_0\, r}$ with P_0: local period in r_0, $\beta=\pi/4$

Period: p_{min}-p_{max}

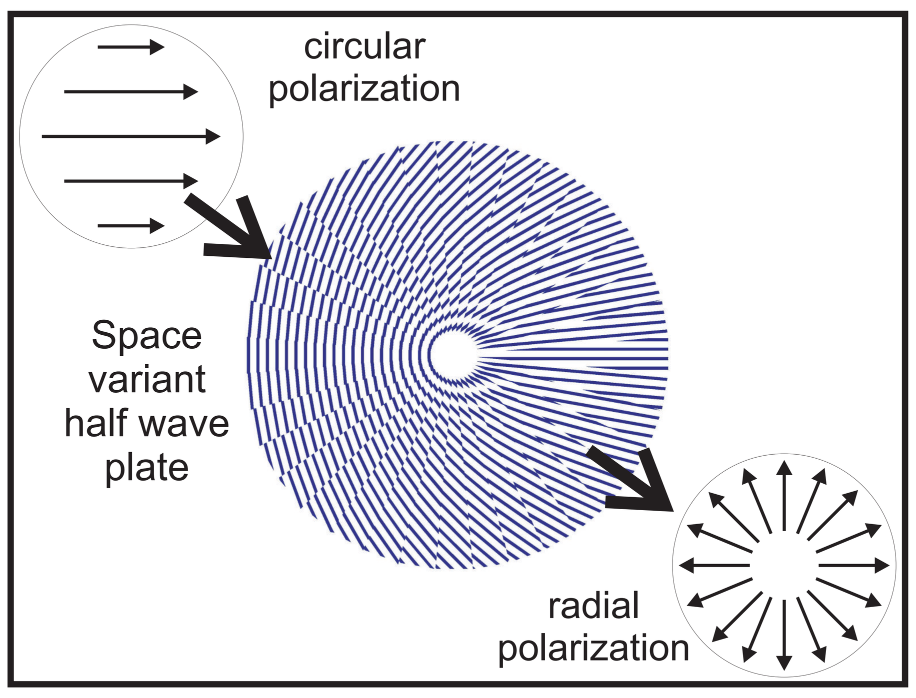
p_{min}: limited by the fabrication
p_{max}: limited throw the wood anomaly

→ Segmentation of r

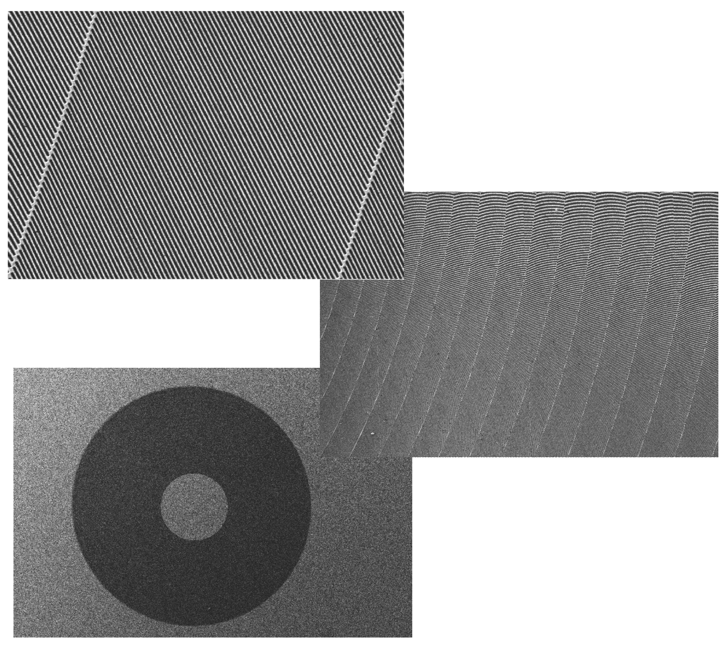
Space variant half wave plate [2]:

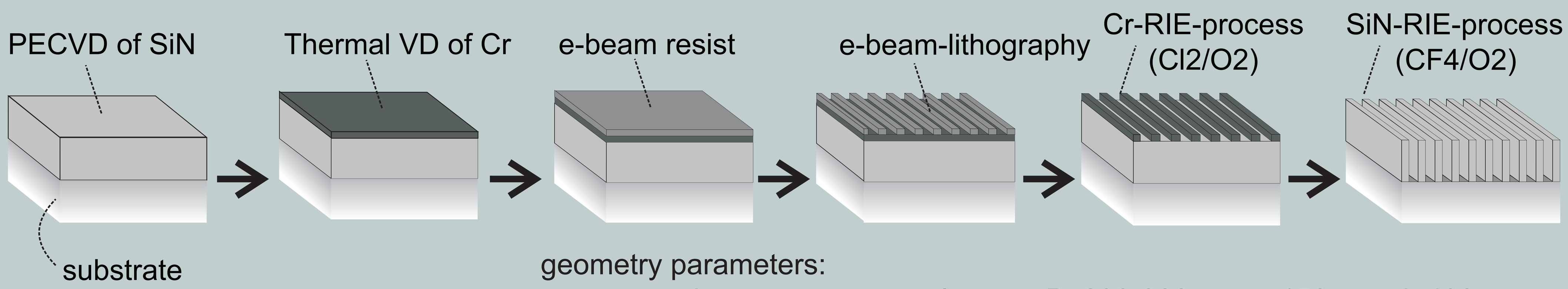
$K_0 = \frac{2\pi}{P}\cos(\theta/2)$ with P: constant period, $\beta=\theta/2$

→ Segmentation of θ

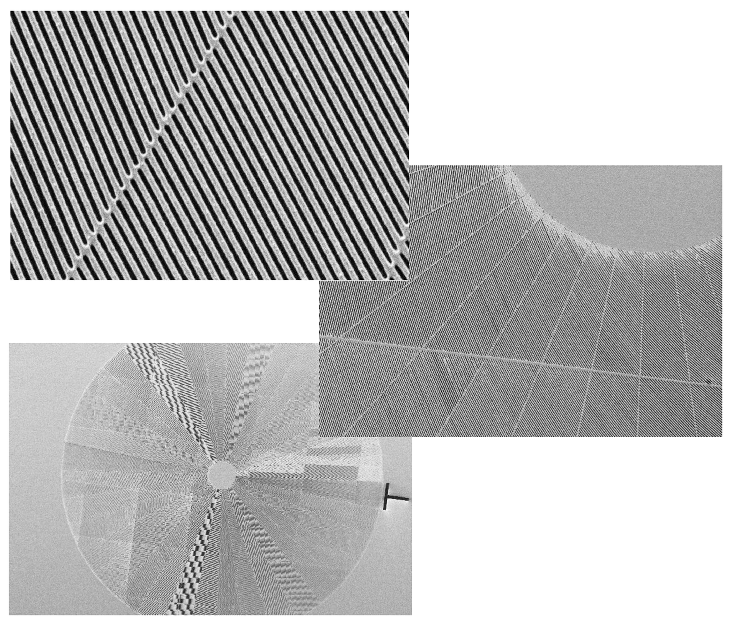


Fabrication

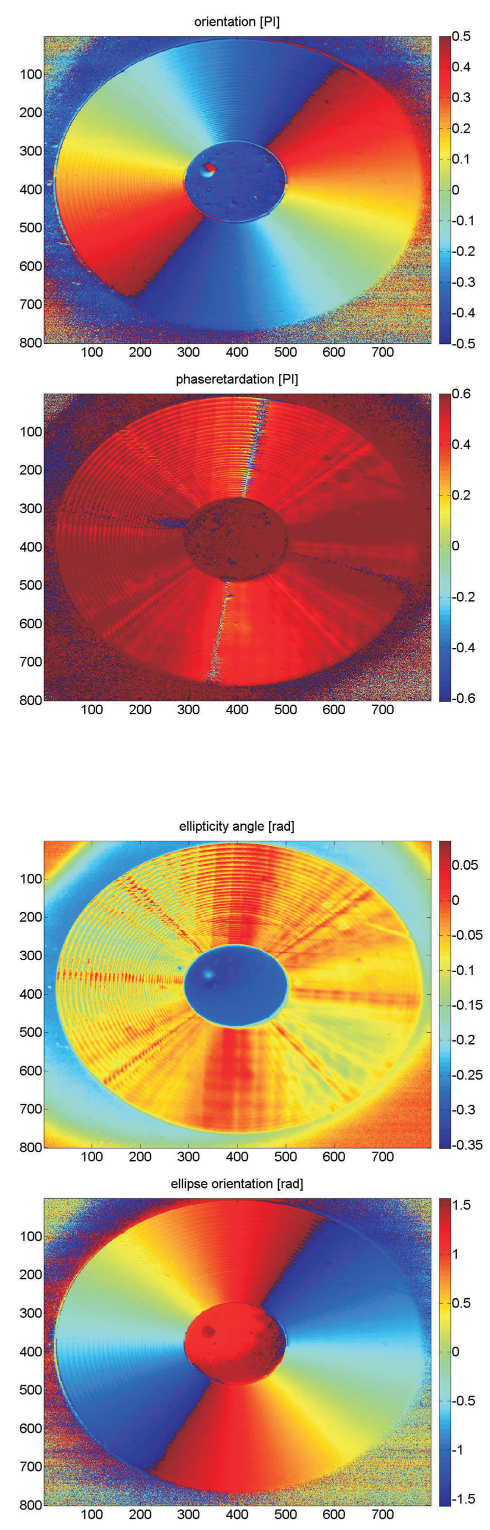


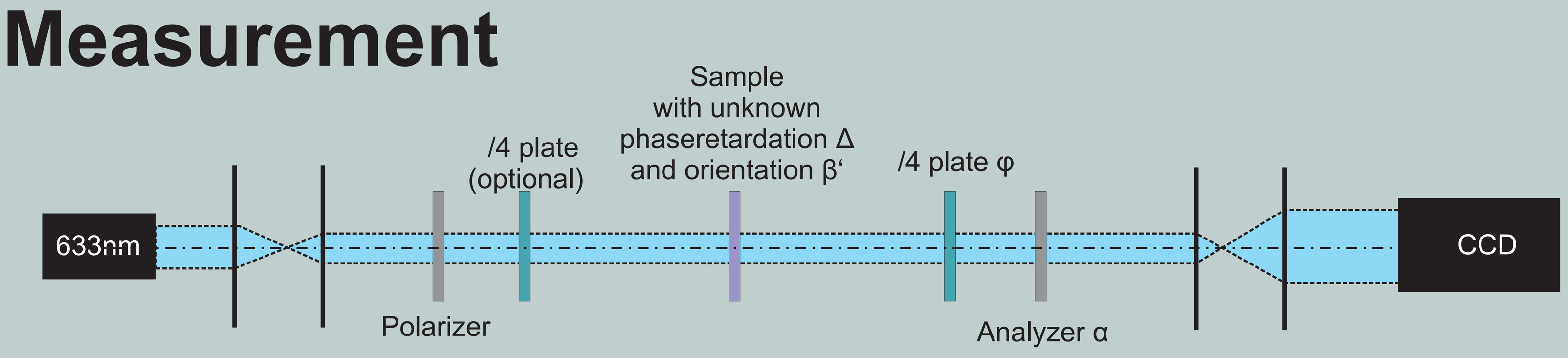


geometry parameters:
- space variant quarter wave plate: P=290-300nm; t=150nm; d=490nm;
- space variant half wave plate: P=300nm; t=120nm; d=1μm;



Measurement





- **Characterization of polarization properties [3]:**

6Shift-Measurement of phase-retardation and orientation of sub-wavelength grating

Polariser 90°, QWP_1 45°: $I = I_b + I_m[\cos\Delta \sin 2(\alpha-\varphi) - \sin\Delta \sin 2(\beta'-\varphi)\cos 2(\varphi-\alpha)]$

Nr.	φ	α	Intensity
1	0	π/4	$I_1 = I_b + I_m\cos\Delta$
2	0	3π/4	$I_2 = I_b - I_m\cos\Delta$
3	π	0/2	$I_3 = I_b - I_m\sin\Delta\sin 2\beta'$
4	π/4	π/4	$I_4 = I_b + I_m\sin\Delta\cos 2\beta'$
5	π/2	π/2	$I_5 = I_b + I_m\sin\Delta\sin 2\beta'$
6	3π/4	3π/4	$I_6 = I_b - I_m\sin\Delta\cos 2\beta'$

Orientation β' of a fast axis of the grating:

$2\beta' = \tan^{-1}\left(\frac{I_5 - I_3}{I_4 - I_6}\right)$

Phase retardation Δ of the grating:

$\Delta = \tan^{-1}\left(\frac{2(I_5 - I_4)(\sin 2\beta' - \cos 2\beta')}{(I_4 - I_6)}\right)$

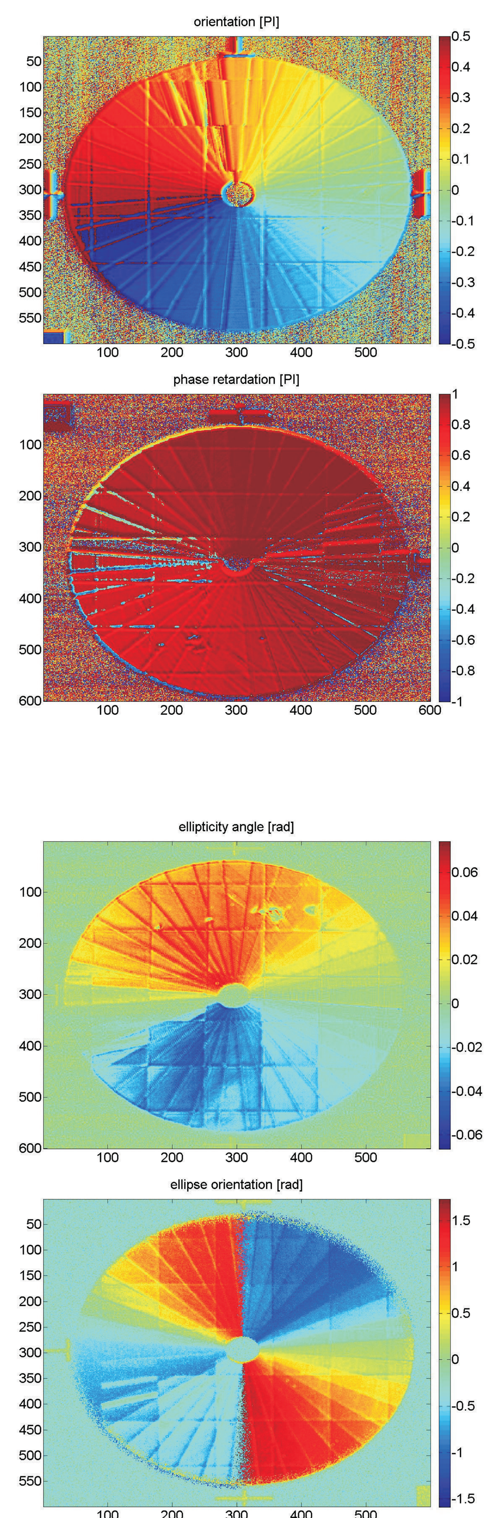
- **Characterization of outgoing light [4]:**

QWP_2 is rotated by angle φ in N=16 steps => intensity measurement $I(\varphi_n)$

$I(\varphi) = \frac{1}{2}[(S_0 + \frac{S_1}{2}) + \frac{S_1}{2}\cos 4\varphi + \frac{S_2}{2}\sin 4\varphi - S_3 \sin 2\varphi]$

Ellipse orientation ψ: $\tan\psi = S_2/S_1$

Ellipticity angle χ: $\sin\chi = S_3/S_0$



Literatur:
[1] Z. Bomzon, G. Biener, V. Kleiner, E. Hasman, "Rad. and azim. polarized beams generated by space-variant dielectric subwavelength gratings", OPTICS LETTERS Vol. 27, No. 5 (2002)
[2] G. M. Lerman, U. Levy, "Generation of a radially polarized light beam using space-variant subwavelength gratings at 1064 nm", OPTICS LETTERS Vol. 33, No. 23 (2008)
[3] A. Asundi, L. Tong, C. G. Boay, "Phase-shifting method with a normal polariscope", APPLIED OPTICS Vol. 38, No. 28 (1999)
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