Diamond subwavelength gratings for mid-infrared AGPM coronagraph: manufacturing assessment

collaborators  S. Habraken, M. Karlsson, F. Nikolajeff, P. Forsberg, M. Kuittinen and I. Vartianen

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What is a phase mask coronagraph?

- **Aim**: direct imaging of high contrast astronomical scenes (e.g. exoplanets)
- **Major constrains**: huge contrast ($10^6$ in the thermal IR) and proximity: 1” at 10 parsecs (Jupiter-like planets)
- **Coronagraph** = “hide” the star to unveil the hidden planet

Transitions: loss of information
Chromaticity: poor Signal to Noise ratio

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The Annular Groove Phase Mask (AGPM)

- Proposed by Mawet et al. 2005
- Zeroth Order (sublambda => period < \lambda/n) Grating (ZOG)
- Form birefringence $\Delta \phi_{TE-TM} = \pi$ $\rightarrow$ phase retarders
- Achromatic on wide spectral bands (in the visible or IR)

FQPM (Four Quadrant Phase Mask)

Vector Vortex Coronagraph (VVC)
360° discovery space

AGPM (Annular Groove Phase Mask)
Other techniques for VVCs, easier to implement, exist: e.g. liquid-crystal polymers (LCP), Mawet et al. 2010

😊 lab demos in the visible and near-IR
😊 used on Palomar in the H- and K-bands
😊 technically limited to the K-band

In fact, these are limited to the visible and near-IR whereas the AGPM is suitable for any spectral band, from the visible to the thermal IR
Which spectral band?

L-band (3.5 – 4.1 µm)

- recent success with NAOS-CONICA (Lagrange et al. 2010)
- important gain in the 0.1-0.5" region, compared to APP+PSF substraction (see O. Absil’s poster)

N-band (8 – 13 µm)

- the AGPM is foreseen for the upgrade of VISIR, and candidate for METIS on the future E-ELT
- subwavelength gratings are one of the only solutions at this wavelength
Which substrate material?

CVD diamond

- Large spectrum: from visible to thermal-IR (~20 µm)
- Favorable mechanical and thermal properties
- High refractive index = shallow etching

Simulations based on the Rigorous Coupled Wave Analysis (RCWA)

E.g. in the N-band

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Inter-University collaboration:

- e-beam mask at the University of Joensuu, Finland (M. Kuittinen and I. Vartianen)

- Nano-Imprint Lithography (NIL) and Reactive Ion Etching at the University of Uppsala, Sweden (M. Karlsson, F. Nikolajeff, P. Forsberg)

- Metrology and optical testing at the University of Liège, Belgium
First manufactured diamond AGPM

Classical metrology + moulding

- interferometry
- SEM, AFM
- silicone moulding
- profile metrology

Defractometry + scattering measurements

- optical bench
- HeNe laser (632.82 nm)
- 5 orders
- total integrated scattering (TIS) = < 0.4% (N-band)
  < 2.3% (L-band)

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First manufactured diamond AGPM

- optimised for [10.5\(\mu\text{m} - 12.25\  \mu\text{m}]

- performances simulated with RCWA (= mean Null Depth @ \(2\lambda/D\))
  - near the center: \(\mu \approx 10^{-5}\)
  - away from the center: \(\mu \approx 10^{-3}\)

- foreseen for the upgrade of VISIR

poor optical quality in the area away from the center, because of too small substrate (1cm diameter)

→ NIL process being improved
→ bigger substrates (2cm diameter)
Components currently being manufactured

L-band

- [3.5 µm – 4.1 µm]: $\mu \approx 5 \times 10^{-6} \ @ \ 2\lambda/D$

→ RCWA simulations:

N-band: 2 components

- [8 µm – 10.5 µm]: $\mu \approx 2 \times 10^{-6} \ @ \ 2\lambda/D$
- [9 µm – 13 µm]: $\mu \approx 3 \times 10^{-5} \ @ \ 2\lambda/D$

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Summary

• The first diamond prototype has been manufactured

• Good metrology → parameters well known

• Possible use on the sky with the future upgrade of VISIR at $[10.5\mu m - 12.25 \mu m]$ with an expected $\mu \approx 10^{-3}$-$10^{-5}$ @ $2\lambda/D$

• Lessons learned, microfabrication techniques improved

• Next components are currently being manufactured with expected performances $\mu < 10^{-5}$ @ $2\lambda/D$

• We focus on the L-band for NACO where the AGPM is very promising
Thank you for your attention!