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

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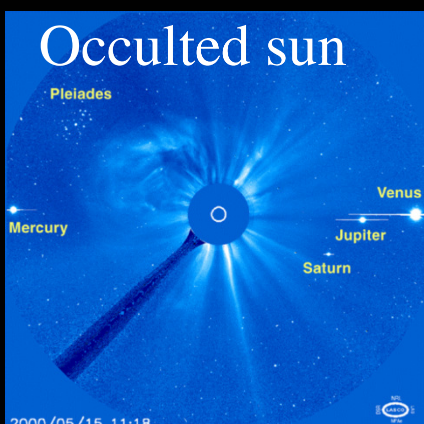
HOLOLAB – Optics laboratory

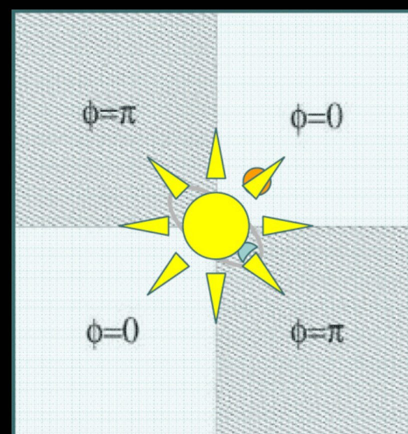
University of Liège

What is a phase mask coronagraph?

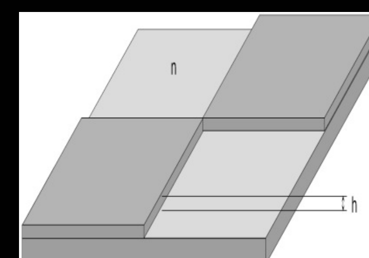
- Aim : direct imaging of high contrast astronomical scenes (e.g. exoplanets)
- Major constrains :
  - huge contrast (10^6 in the thermal IR)
  - proximity : 1'' at 10 parsecs (Jupiter-like planets)
- Coronagraph = "hide" the star to unveil the hidden planet



→ Amplitude mask



Star
→ phase mask



→ FQPM *(Four Quadrant Phase Mask)*

Transitions : *loss of information*

Chromaticity : *poor Signal to Noise ratio*

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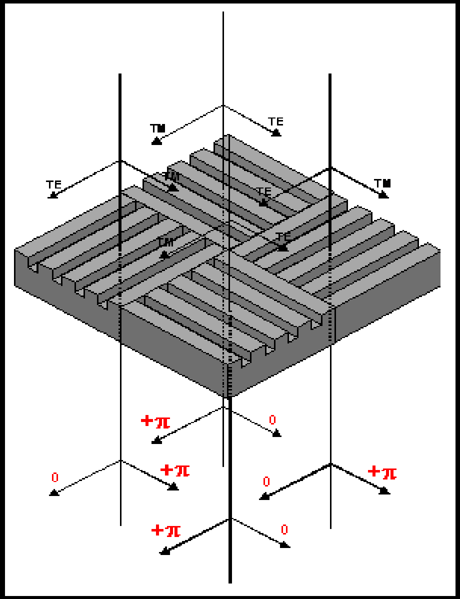
The Annular Groove Phase Mask (AGPM)

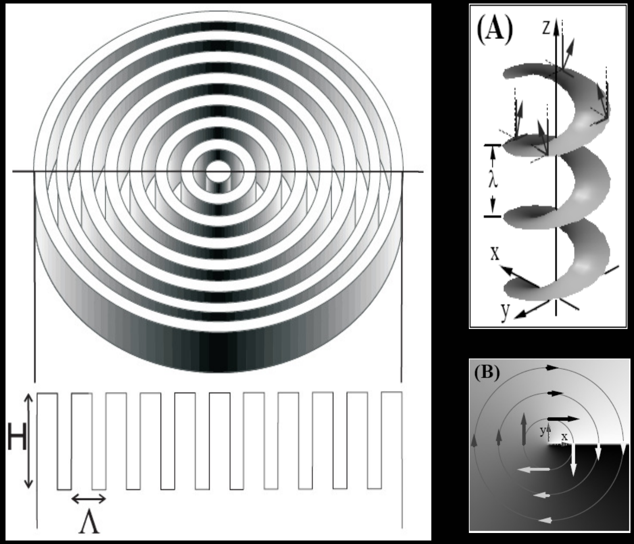
- Proposed by Mawet et al. 2005
- Zeroth Order (sublambda => period < λ/n) Grating (ZOG)
- Form birefringence → $\Delta\Phi_{TE\text{-}TM} = \pi$ → phase retarders
- Achromatic on wide spectral bands (in the visible or IR)



FQPM *(Four Quadrant Phase Mask)*

Vector Vortex Coronagraph (VVC)

360° discovery space



AGPM *(Annular Groove Phase Mask)*

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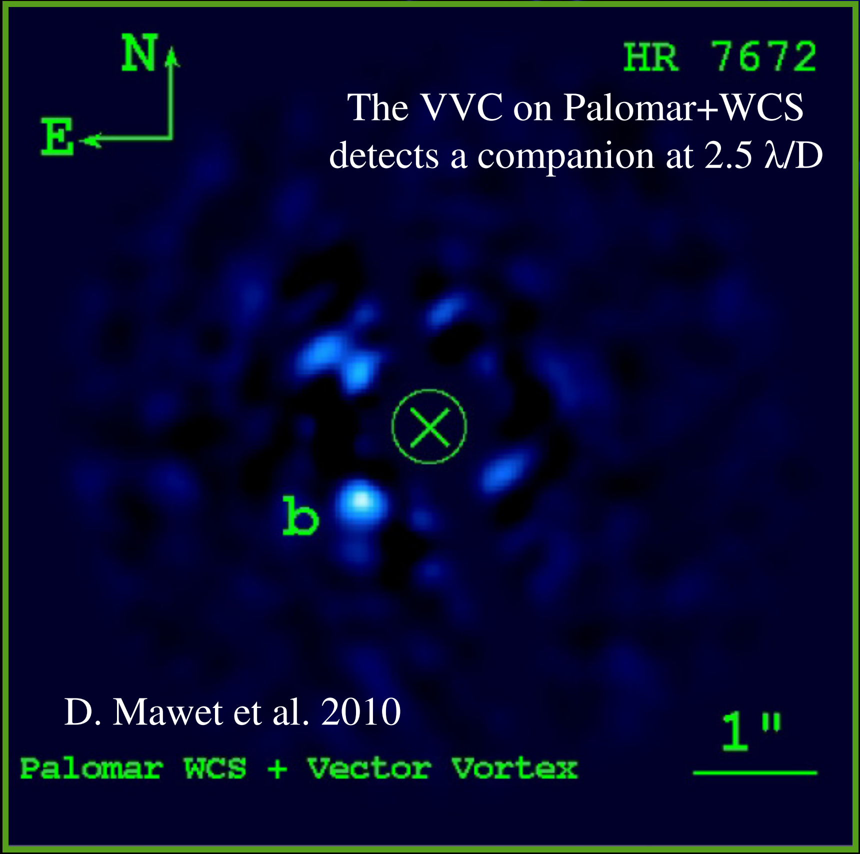
Which spectral band ?

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 ?

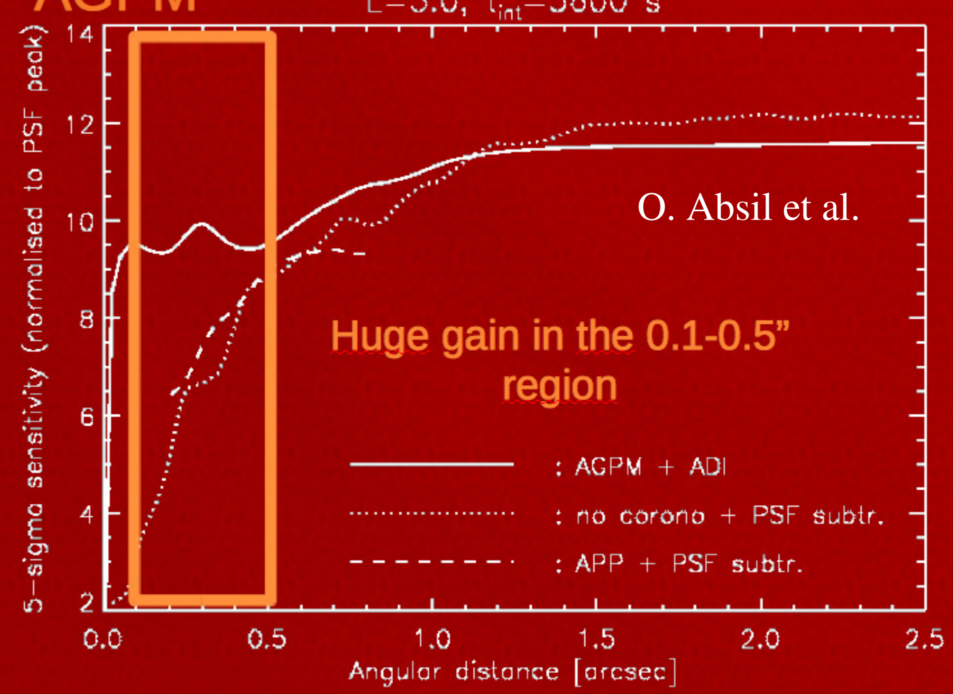
L-band (3.5 – 4.1 μm)

- 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

End-to-end simulations of NACO-AGPM



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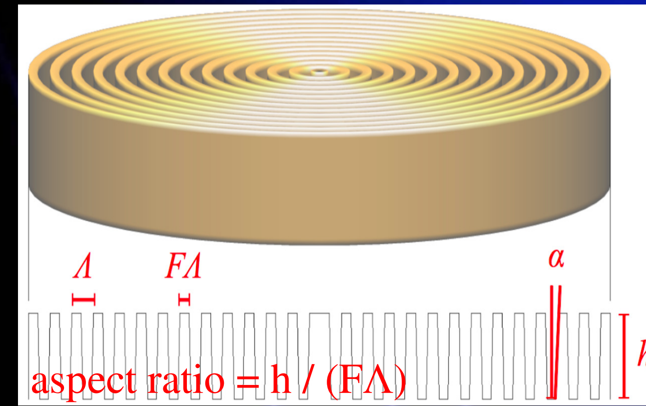
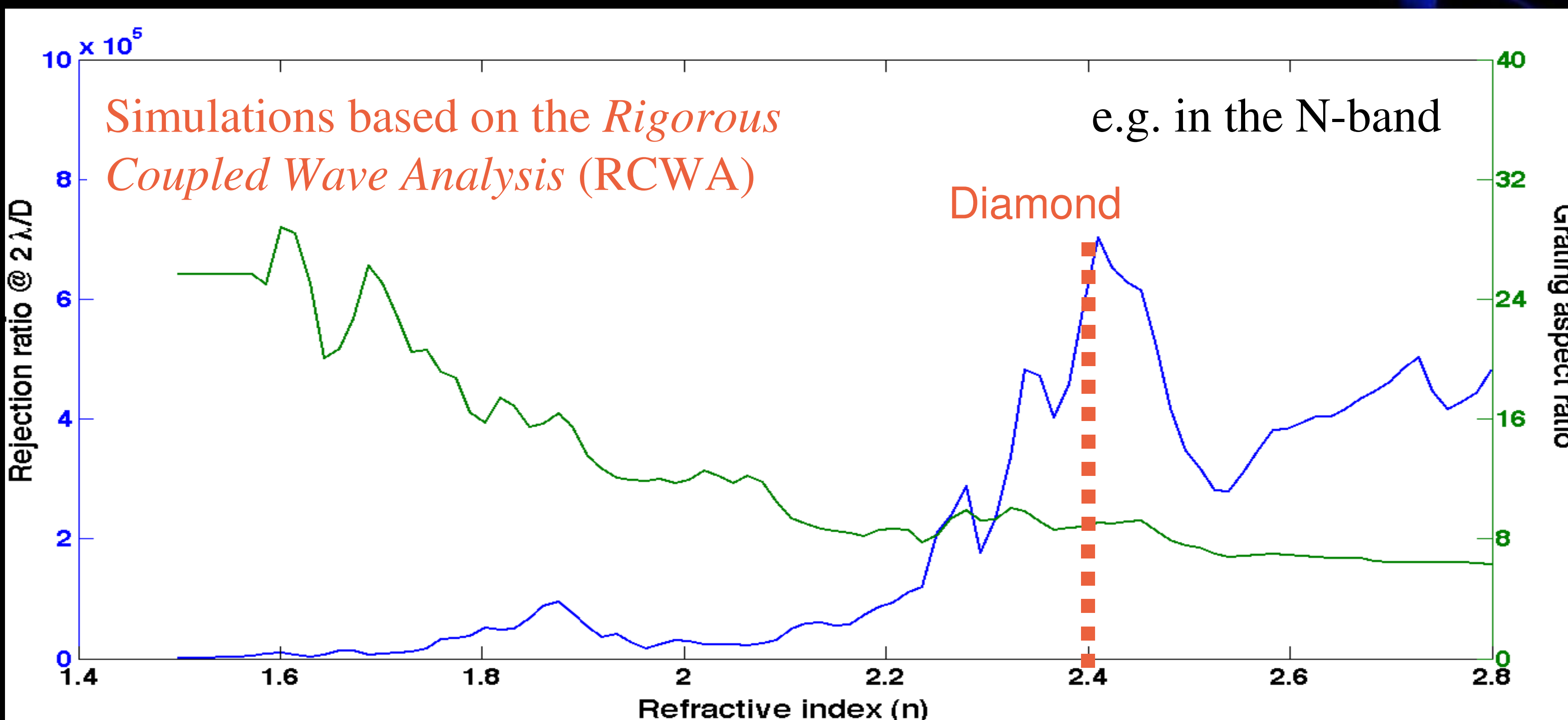
Which substrate material ?



CVD diamond

☺ large spectrum : from visible to thermal-IR (~ 20 μm)
☺ favorable mechanical and thermal properties
☺ high refractive index = shallow etching



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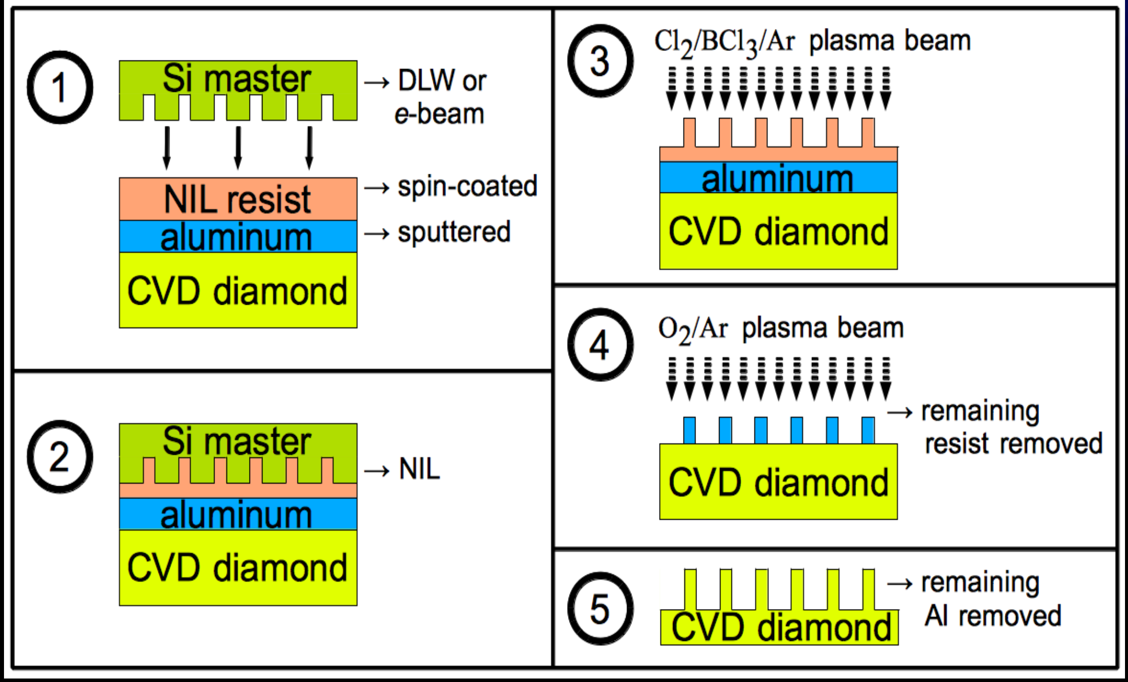
First manufactured diamond AGPM

Manufacturing process

Inter-University collaboration:

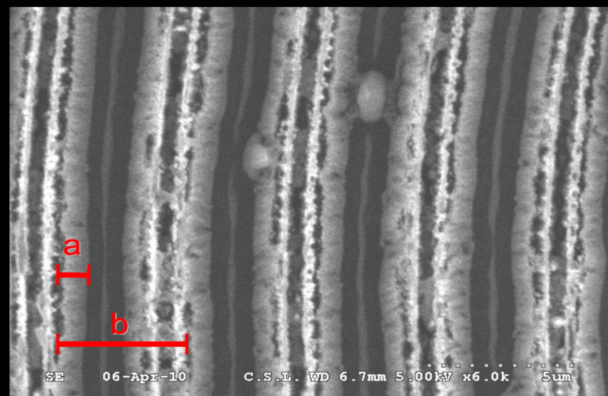
- e-beam mask at the University of Joensuu, Finland (M. Kuittinen and I. Vartianen)
- Nano-Imprint Lithography (NIL) and Reactive Ion Etching at the University of Uppsala, Sweden (M. Karlsson, F. Nikolajeff, P. Forsberg)
- Metrology and optical testing at the University of Liège, Belgium

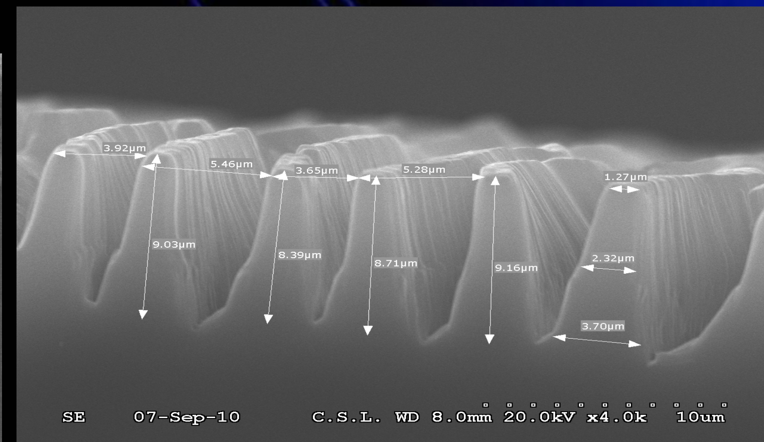


First manufactured diamond AGPM

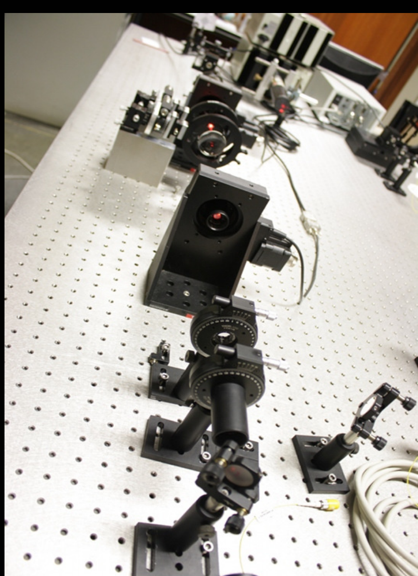
Classical metrology + moulding

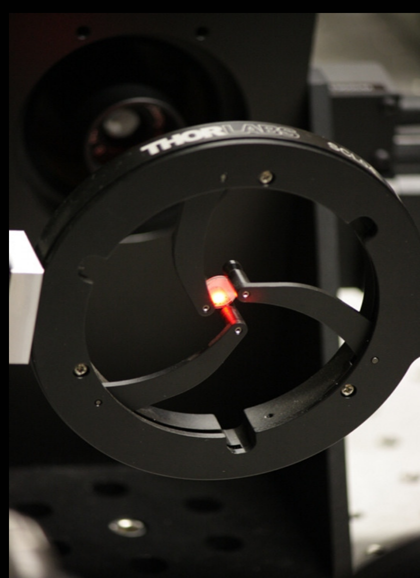
- interferometry
- SEM, AFM
- silicone moulding
- profile metrology

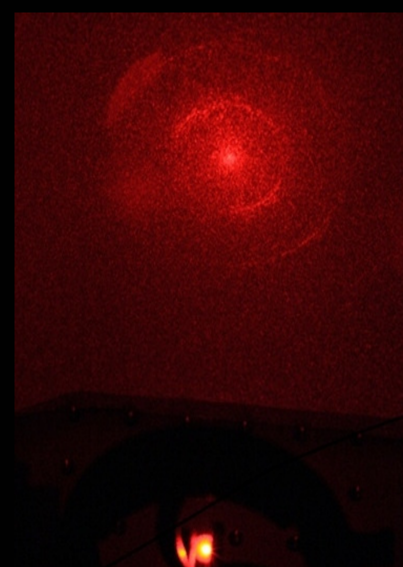




Defractometry + scattering measurements







- 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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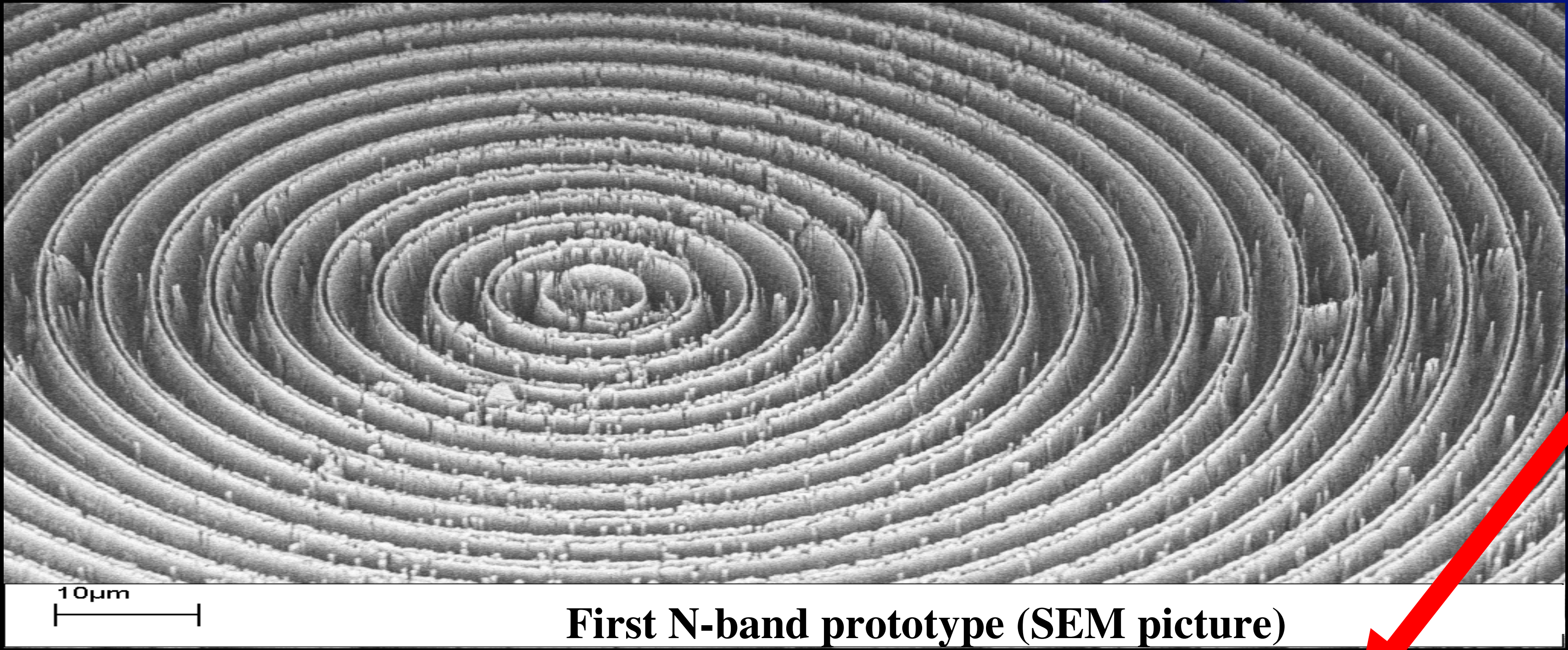
First manufactured diamond AGPM



First N-band prototype (SEM picture)

- optimised for [10.5µm – 12.25 µm]

- performances simulated with RCWA

(= mean Null Depth @ 2λ/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)

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Components currently being manufactured

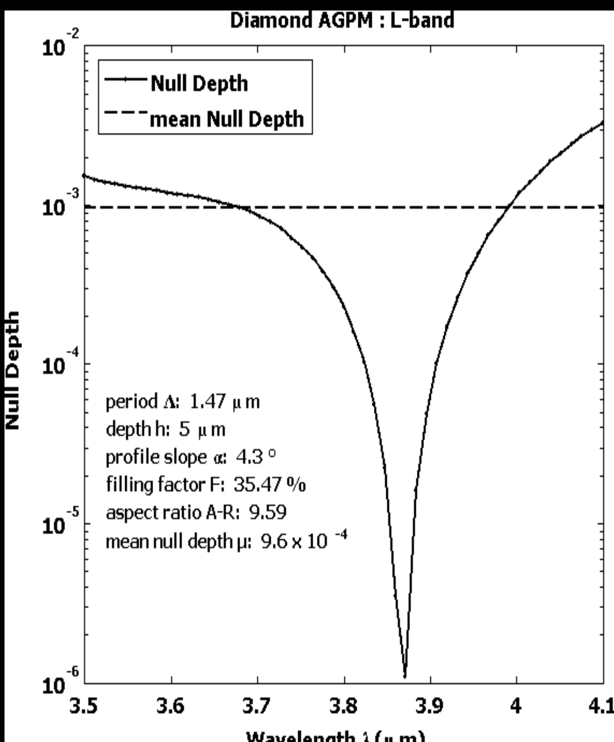
L-band

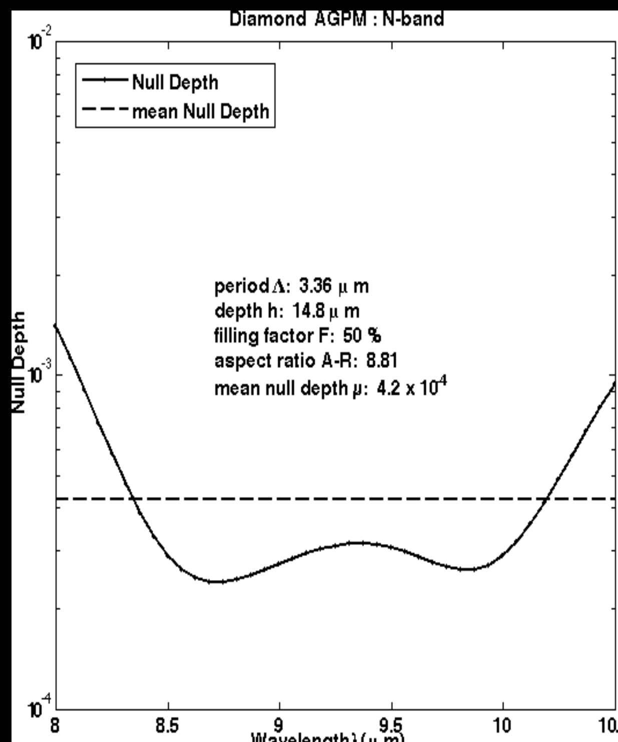
- [3.5 µm – 4.1 µm]: $\mu \approx 5\times10^{-6}$ @ $2\lambda/D$

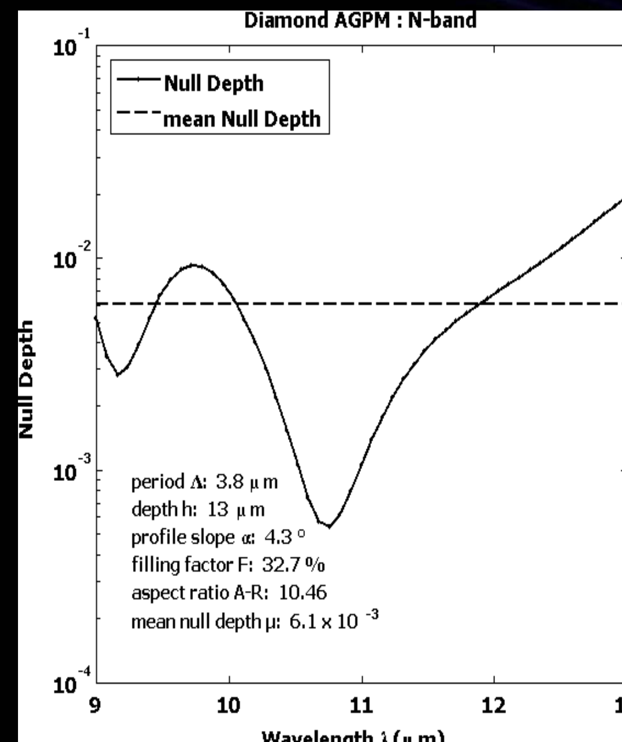
N-band : 2 components

- [8 µm – 10.5 µm]: $\mu \approx 2\times10^{-6}$ @ $2\lambda/D$
- [9 µm – 13 µm]: $\mu \approx 3\times10^{-5}$ @ $2\lambda/D$

→ RCWA simulations :







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 [10.5µm – 12.25 µm] with an expected $\mu \approx 10^{-3}$-10^{-5} @ $2\lambda/D$

- Lessons learned, microfabrication techniques improved

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

- We focus on the L-band for NACO where the AGPM is very promising

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Thank you for your attention !