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# Updates on the PeNCIL project

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**Summary.** — By comparing measured and expected polarization in the HI Ly$\alpha$ 121.6 nm coronal emission line it is possible to infer the magnetic field in the solar corona. PeNCIL is the ideal device to perform such a measurement. It is a light transmitting polarimeter optimized at 121.6 nm, completely free of mechanical moving parts, thought as part of an internally occulted coronagraph to be flown aboard a future small solar mission. Its optical components are in de Senarmont configuration: a fixed $MgF_2$ quarter wave retarder, a nano-wire grid polarizer (nano-WGP) and a $MgF_2$ variable retarder modulated through a calibrated piezo-clamp (PCVR). The nano-WGP and the PCVR represent a first-ever achievement in the history of technology development for VUV. The nano-WGP fabrication is at the edge of the current nanotechnology since the pitch between wires shall be 40 nm. The PCVR is based on a $MgF_2$ parallelepipedic sample refractive index variations as produced by a piezo-electric clamp. This work addresses the status of the project with particular emphasis on the design and manufacturing of the nano-WGP and the PCVR.

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## 1. – Introduction

The magnetic field rules the physics of the corona, thus influencing the phenomena of the whole heliosphere. The magnetic field in corona can be measured through the Hanle effect, which is the induced modification -due to the magnetic field- of the linear polarization signals produced by anisotropic scattering processes. The HI Lyman $\alpha$ 121.6 nm emission line is the most intense of the EUV coronal spectrum and is highly sensitive to the Hanle effect. By comparing measured and expected polarization (to be theoretically estimated) in the HI line it is possible to infer the magnetic field in corona. PeNCIL (PolarimEtry with Nanowires for Coronal Imaging of Ly alpha) may constitute the ideal candidate to map the linear polarization of the whole Ly$\alpha$ 121.6 nm corona. It is a transmitting polarimeter optimized at 121.6 nm, thought as part of an internally occulted coronagraph to be flown aboard a future small solar mission or a sounding rocket. It is a light device, completely free of mechanical moving parts. Its optical components are in de Senarmont configuration: a fixed $MgF_2$ quarter wave retarder, a nano-wire grid polarizer (nano-WGP) and a $MgF_2$ variable retarder modulated through a calibrated piezo-clamp (PCVR). Magnesium Fuoride has to be used as substrate, being one of the two materials transparent at 121.6 nm; the other one is LiF, which is unfortunately highly hygroscopic and practically not usable.

The nano-WGP and the PCVR are the two main components of PeNCIL and represent a first-ever achievement in the history of technology development for VUV: sections **2** and **3** are dedicated to the description of their development status.

## 2. – The nano-WGP

In a wire grid polarizer (WGP) the electric field component parallel to the wires is absorbed and only the perpendicular component is transmitted. Wire grid polarizers have larger transmittances than dichroic polarizers, are more achromatic, and have a similar extinction ratio. In the UV, WGP are not easily manufactured, because grid spacing must be around 30% of the working wavelength [1]. A 121.6 nm polarizer must have a spatial period of 40 nm, which is feasible by pushing to the limit the currently available nanotechnologies.

A fabrication flow has been developed and is depicted in figure 1. The polishing

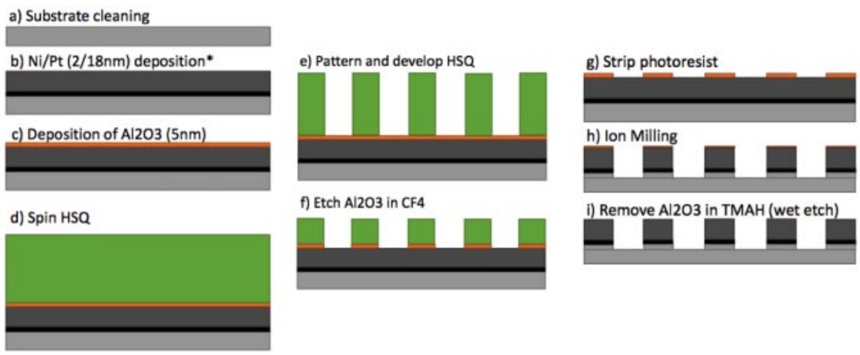


Fig. 1. – Workflow for the fabrication of the nano-WGP plate.

phase -figure 1 (a)- is crucial to the entire process: in order to obtain a regular pattern, a surface roughness $< 0.5$ nm rms and $< 5$ nm peak-to-valley is required. $MgF_2$ is a hard but brittle crystal, standard polishing cannot guarantee the required roughness. In order to obtain those polishing levels, magneto-rehological finishing has been applied to the plates after a cycle of standard polishing. The selected plate had a rms roughness below 0.3 nm and a peak-to-valley less than 4 nm.

Then, layers of Ni (2 nm) and Pt (18 nm) are deposited. Ni is one of the typical adhesion layers for Pt, without Ni, the Pt layer would just lift off the substrate. In order to draw the parallel wires mask by means of electron beam lithography, the chosen resist is HSQ (Hydrogen silsesquioxane), which guarantees a better resolution with respect to the more standard PMMA (poly methyl methacrylate) that was used for the same project in the past [2]. As shown in figure 1 (h), ion milling is being used in order to dig parallel rifts by following the mask. Ion milling using HSQ as a mask is not feasible because the etch rate of HSQ is much higher than the etch rate of Pt. So, a thin layer of $Al_2O_3$ is deposited on the Pt and then HSQ is spun over the sample. As shown in figure 1 (e), e-beam lithography is then used to draw the HSQ mask. By etching $Al_2O_3$ in $CF_4$, the HSQ mask works as a stencil to accurately dig the $Al_2O_3$ layer. Then -figure 1 (g)- HSQ is stripped off from the sample and finally ion milling is performed. A residual thin $Al_2O_3$ layer is removed by a TMAH (tetramethylammonium hydroxide) etching.

## 3. – The Piezoelectric Clamp Variable Retarder

The PCVR is based on a well known principle: by compressing a block of glass along a direction, it is possible to induce a retardance (in waves) defined by $\delta = K \cdot d \cdot \sigma / \lambda$

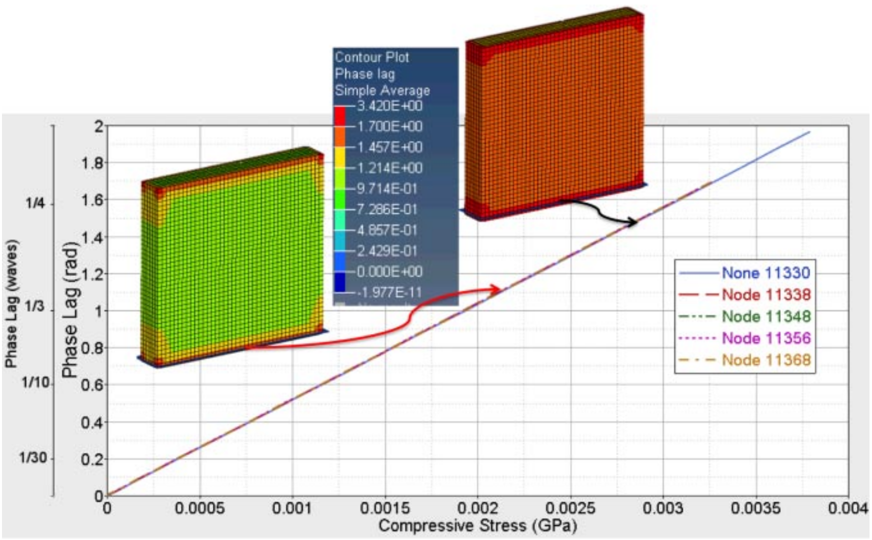


Fig. 2. – Phase retardance (in radians and waves) as a function of the applied compressive stress. The nodes are selected so to sample the crystal. Two snapshots of the FEM simulations (with relative colorbar in radians) corresponding to different compressions are shown as well. Arrows indicate the range of compressive stress that corresponds to the simulation.

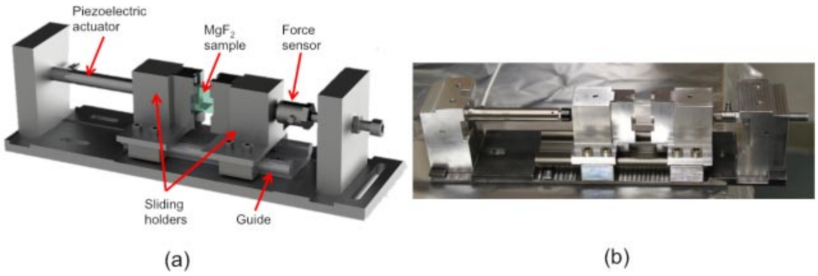


Fig. 3. – (a) a 3D CAD rendering of the PCVR. (b) The actual realization.

where $\sigma$ is the compression strength (a pressure), $K$ is the stress optical coefficient that is a characteristic of the glass type, $d$ is the sample thickness along the optical axis and $\lambda$ is the wavelength.

A compression of $MgF_2$ has never been attempted with this goal. $MgF_2$ is a birefringent crystal with a tetragonal structure, thus the dependence of the retardance on the applied pressure is more complicated with respect to glass. A preliminary study was conducted in order to identify the allowed compression range that could be used not to exceed the elastic limit of the crystal. A summary of the results is shown in figure 2. A couple of snapshots from the FEM (finite element model) simulations (with relative colorbar in radians) are included in the figure. FEM simulations are performed with a sample 20x20x3 mm$^3$, with the compressive stress applied on the upper side and with no friction at the bottom side. Arrows indicate the range on the plot to which each FEM simulation is relative. The graph reports the phase retardance in radians and waves as a function of the applied compressive stress. The retardance was evaluated for several nodes selected so to sample the crystal behaviour in the area interested by the optical light beam. The results for all the nodes are overlapped, which means that the retardance over the interested area can be considered reliably constant. A quarter wave plate can be achieved with an applied stress of 3 MPa, which is well below the elastic limit of $MgF_2$ (50 MPa). A piezo-electric actuator was selected in order to apply the compression. As shown in figure 3 (a), a mechanical clamp is coupled to the piezo-electric actuator in order to apply the compression to both the opposite sides of a $MgF_2$ parallelepipedic sample. The piezoelectric actuator is commanded through static states, corresponding each to a different compression and therefore to a different induced retardance. A calibrated force sensor is positioned on the opposite side with respect to the piezoelectric actuator, in order to monitor the effective applied stress. The manufactured prototype is shown in figure 3 (b).

Calibrations of the PCVR are currently ongoing in order to experimentally characterize the stressed crystal behaviour and to link the actuator fed voltage level to the induced retardance.

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