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Centro Ricerche Portici

Camera for recording light backscattered from photovoltaic samples

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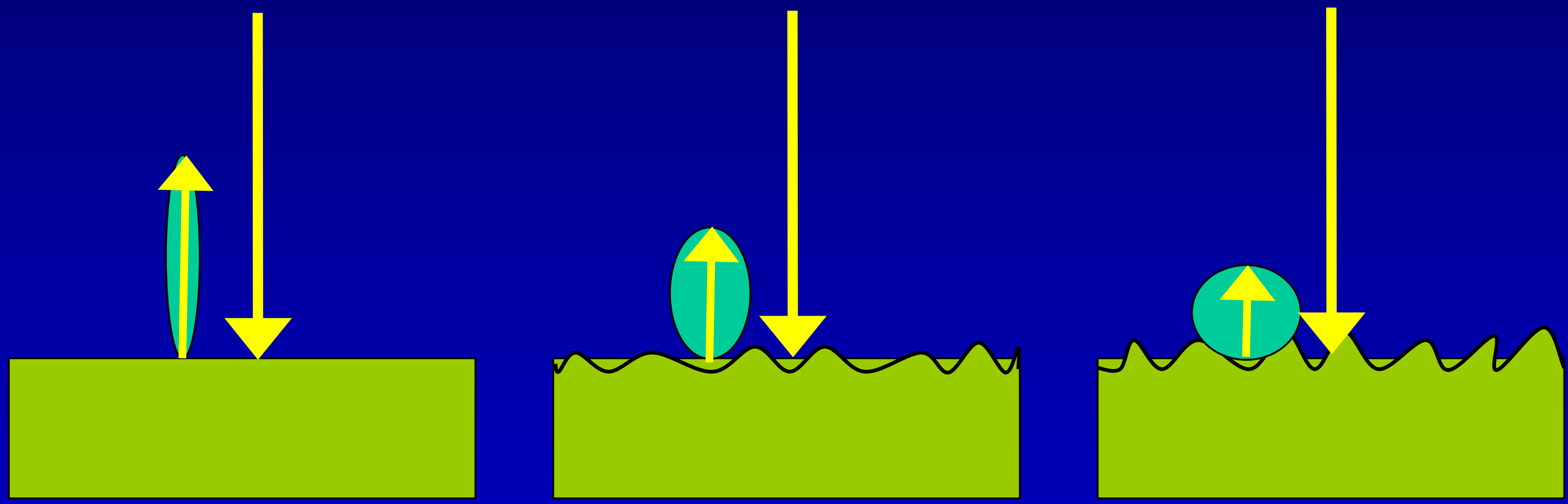
INTRODUCTION

LIGHT BACKSCATTERING FROM PHOTOVOLTAIC SURFACES

Flat silicon surface

Rough silicon surface

Very rough silicon surface



High total reflectance

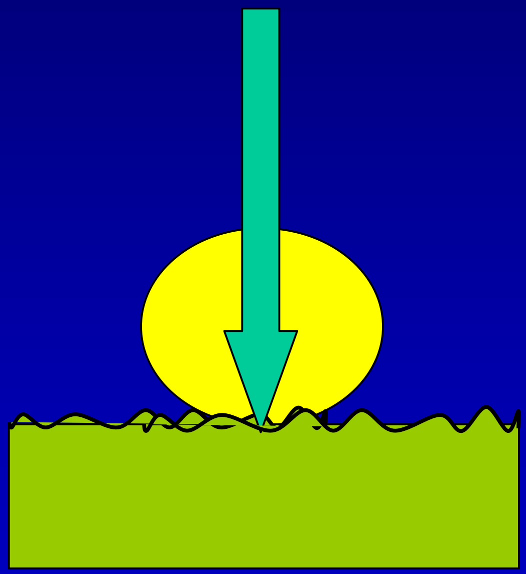
Medium reflectance

Low total reflectance

Surface roughness promotes light trapping and produces spatially distributed reflected light

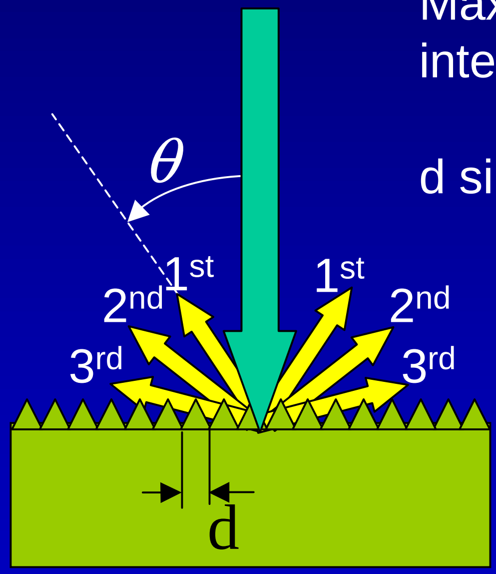
LIGHT BACKSCATTERING FROM PHOTOVOLTAIC SURFACES

Light diffusion



Randomly textured surface

Light diffraction

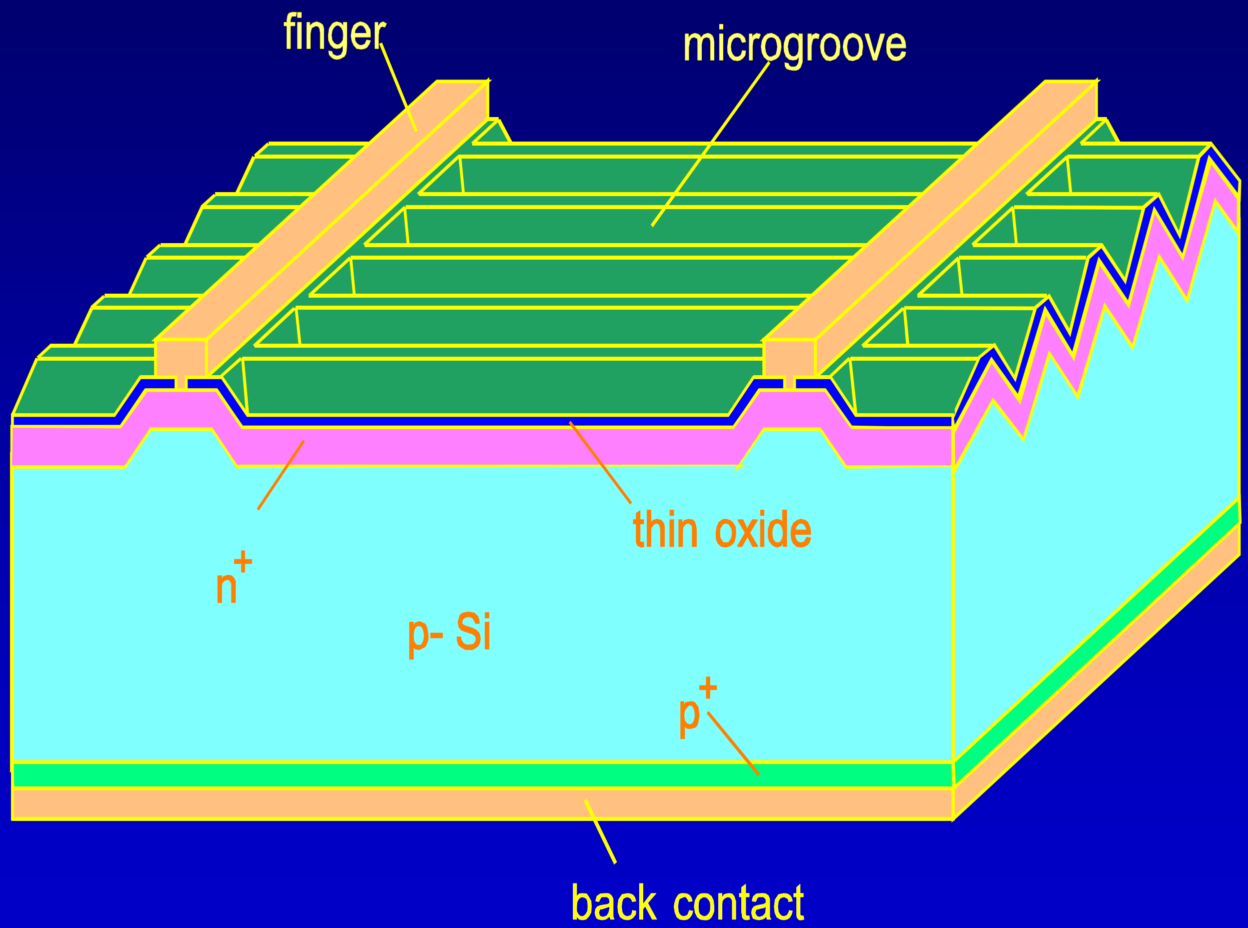


Maxima of intensity:

$$d \sin\theta = k \lambda$$

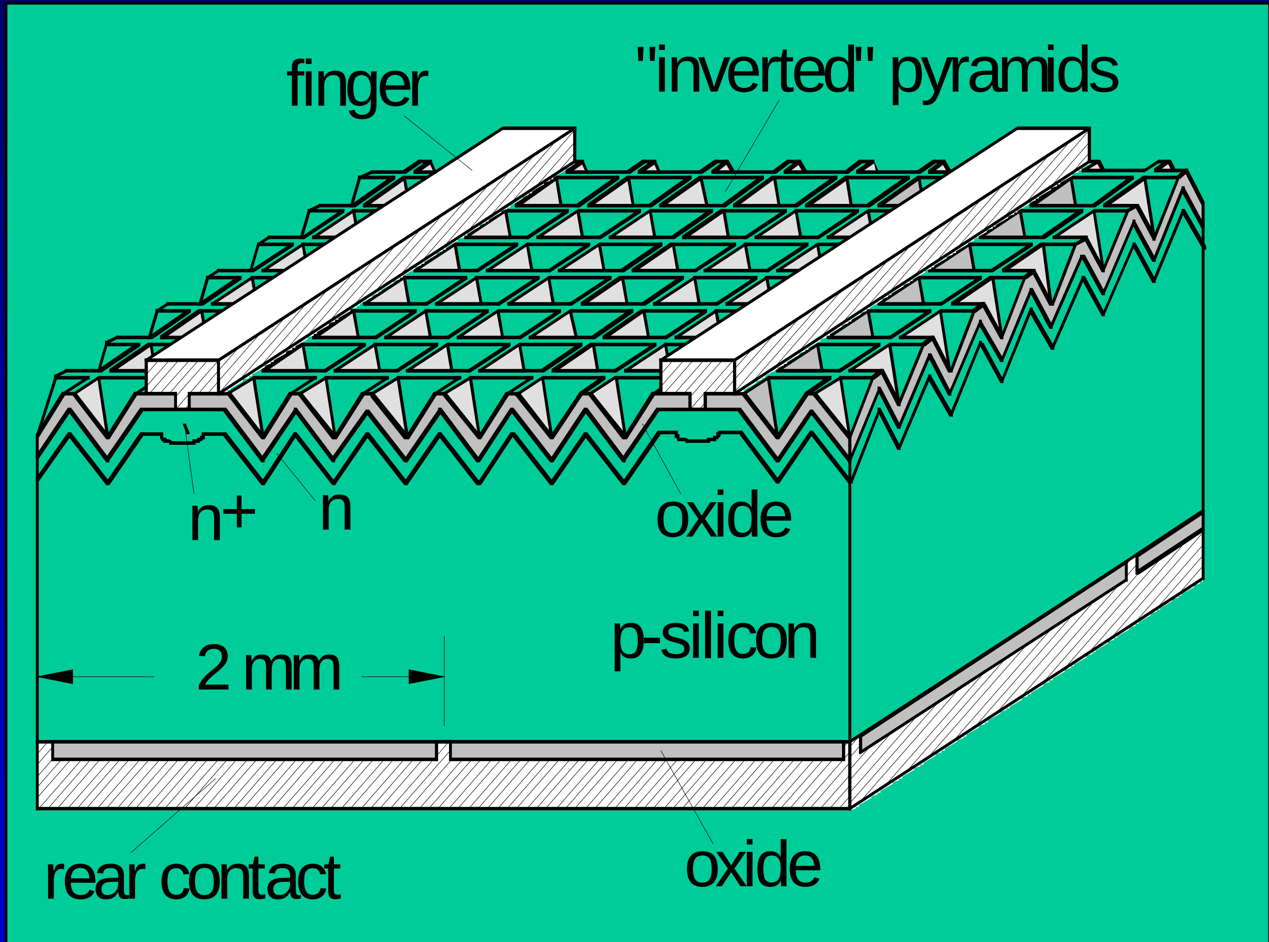
Regularly textured surface

EXAMPLES OF REGULARLY TEXTURED SILICON SURFACES (from UNSW)



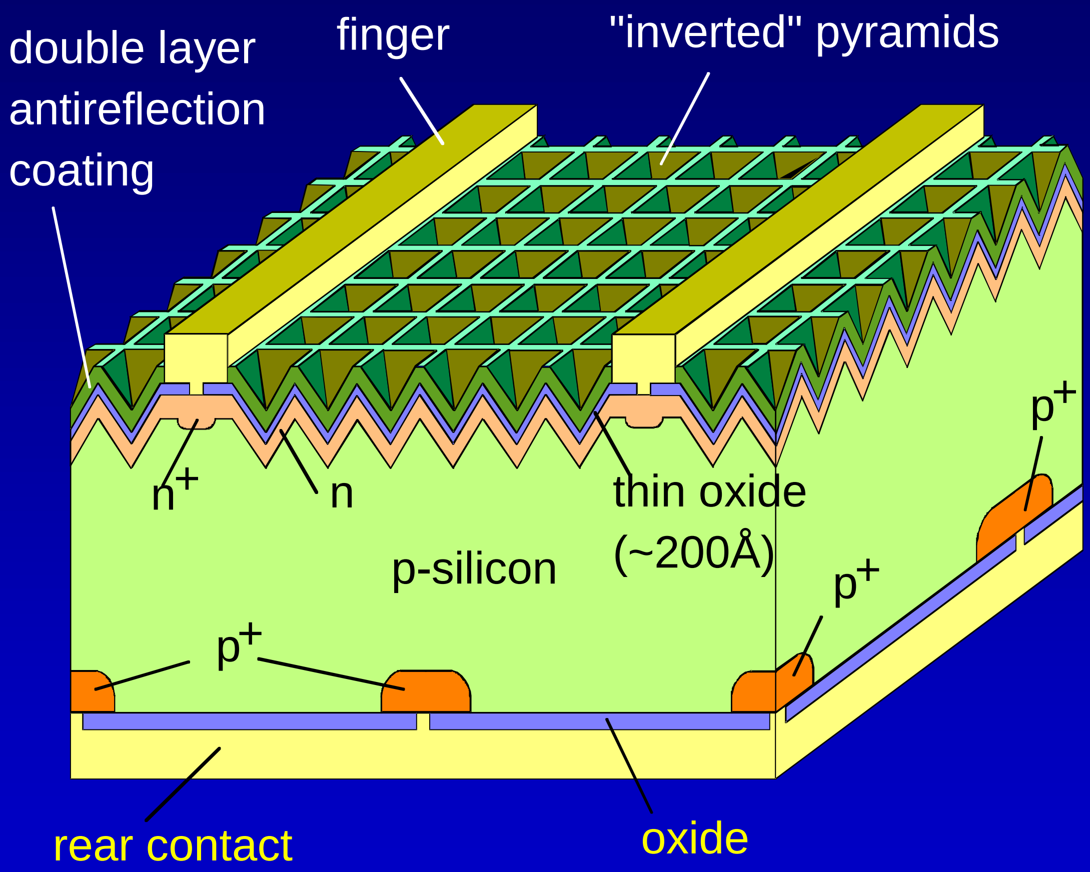
PESC (Passivated Emitter Solar Cell)

EXAMPLES OF REGULARLY TEXTURED SILICON SURFACES (from UNSW)



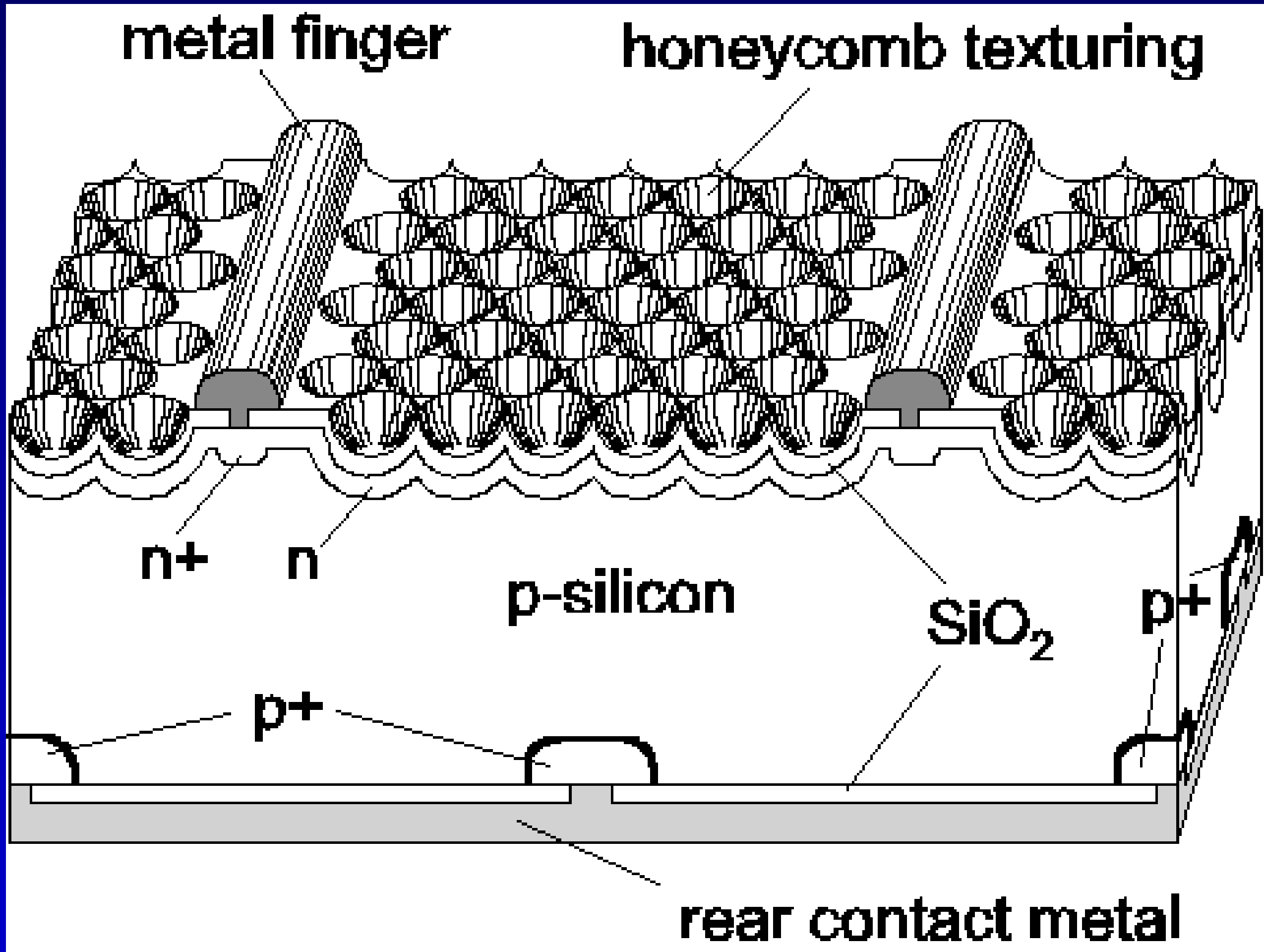
PERC (passivated emitter and rear cell)

EXAMPLES OF REGULARLY TEXTURED SILICON SURFACES (from UNSW)



PERL (Passivated Emitter, Rear Locally-diffused cell)

EXAMPLES OF REGULARLY TEXTURED SILICON SURFACES (from UNSW)

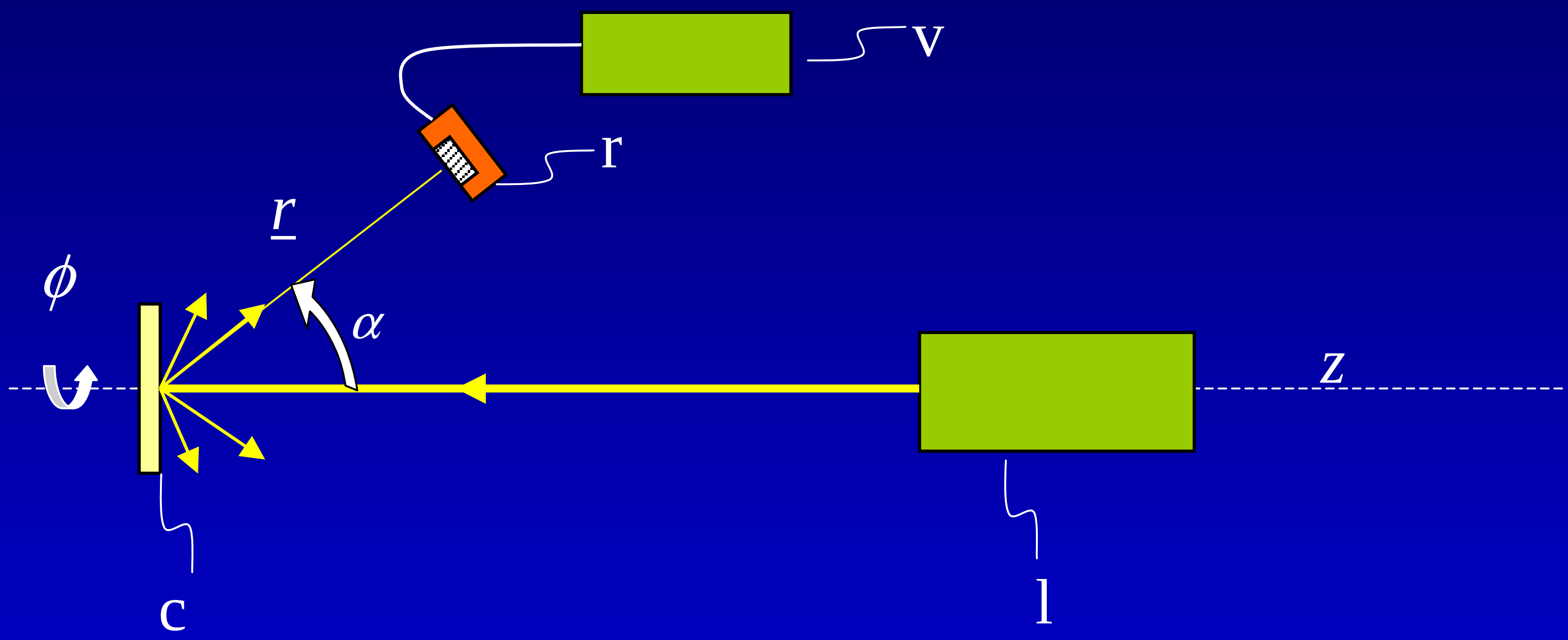


HC (Hoenycomb textured multi-Si cell)

MEASUREMENT OF LIGHT BACKSCATTERED

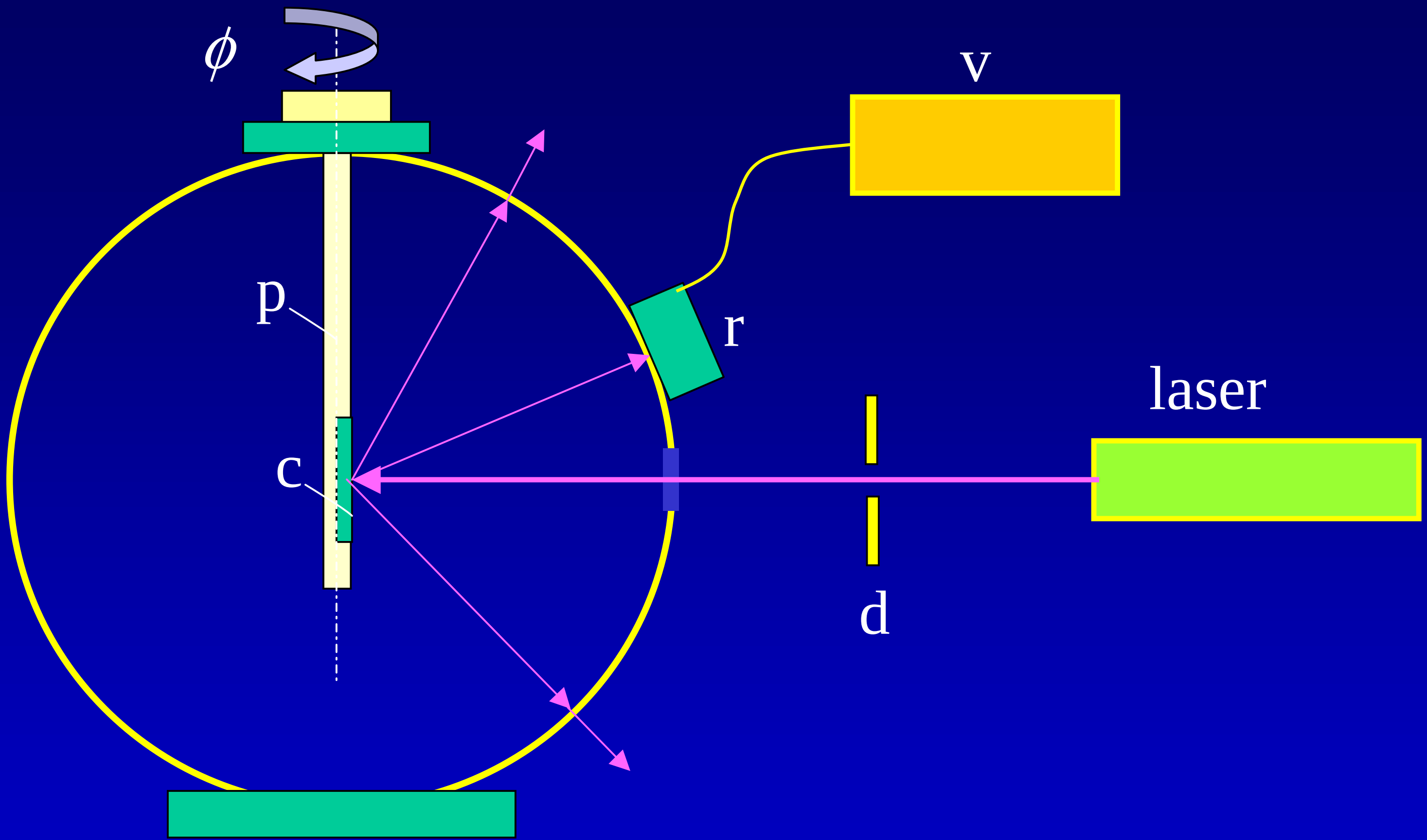
FROM PHOTOVOLTAIC SURFACES

TWO-GONIOMETERS APPARATUS



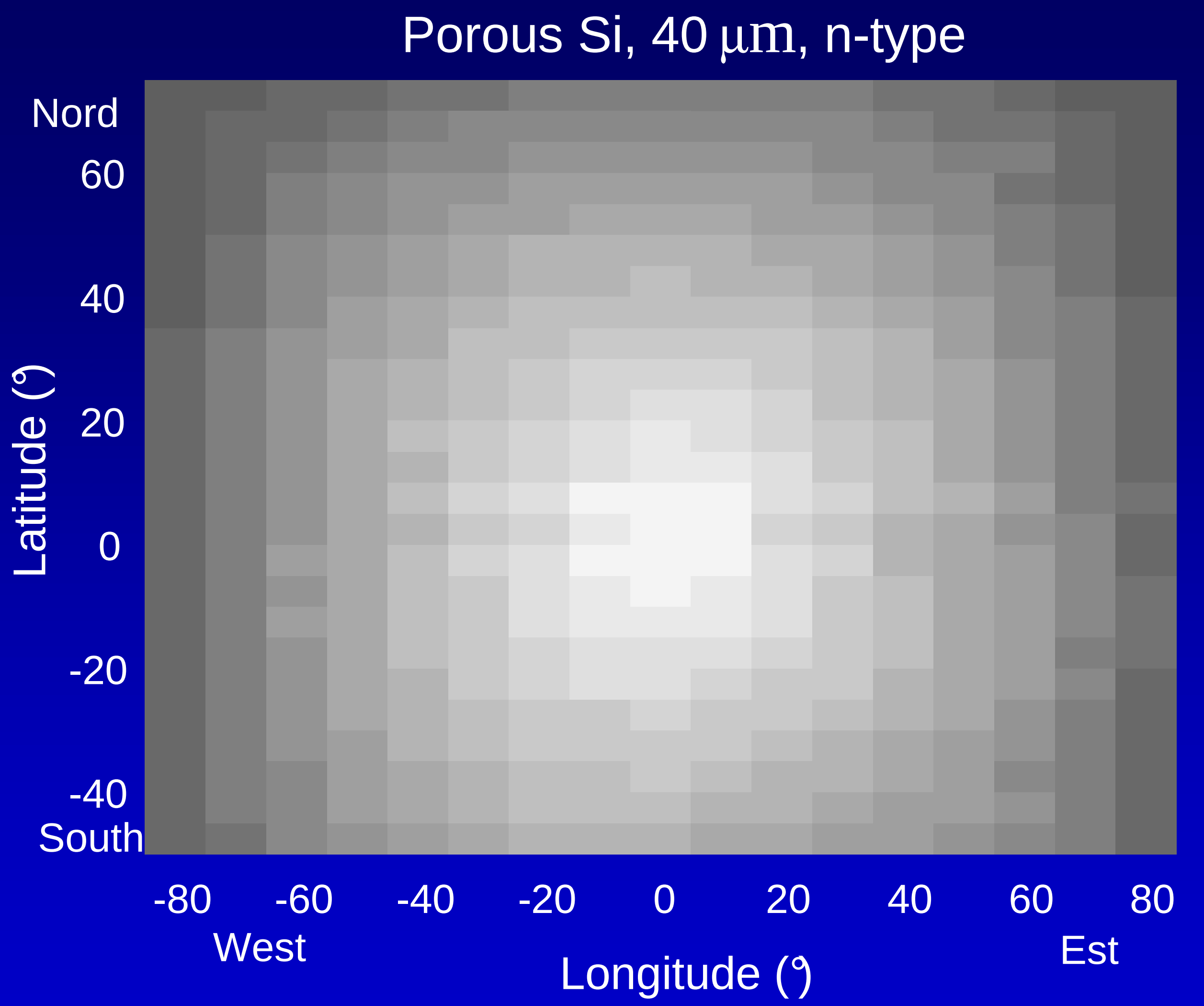
The detector is moved in front of the sample, at constant distance, changing angles α and ϕ by two goniometers.

SEMITRANSPARENT GLOBE



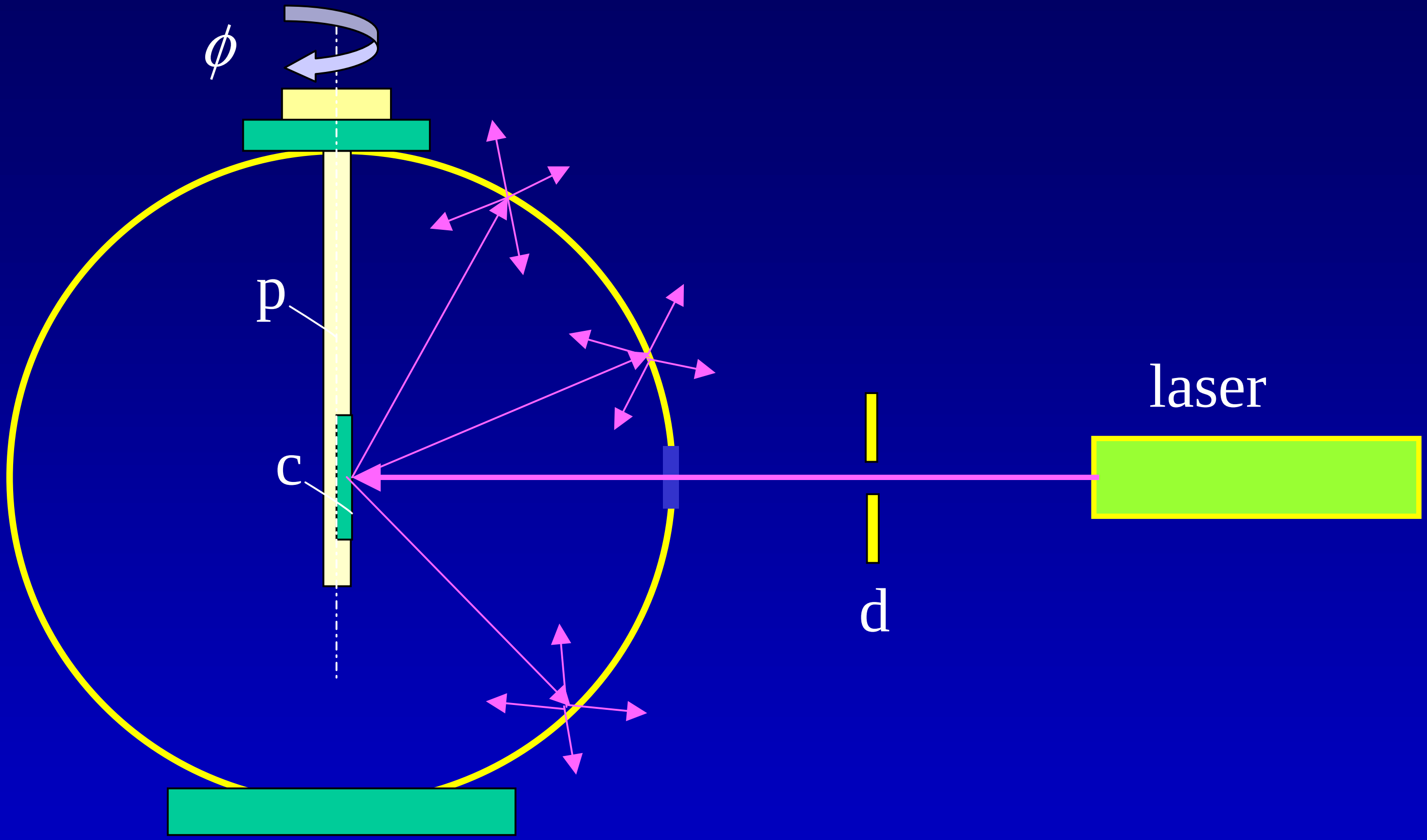
Simple apparatus for backscattered light measurements.
The photodetector is moved over the globe surface.

SEMITRANSPARENT GLOBE



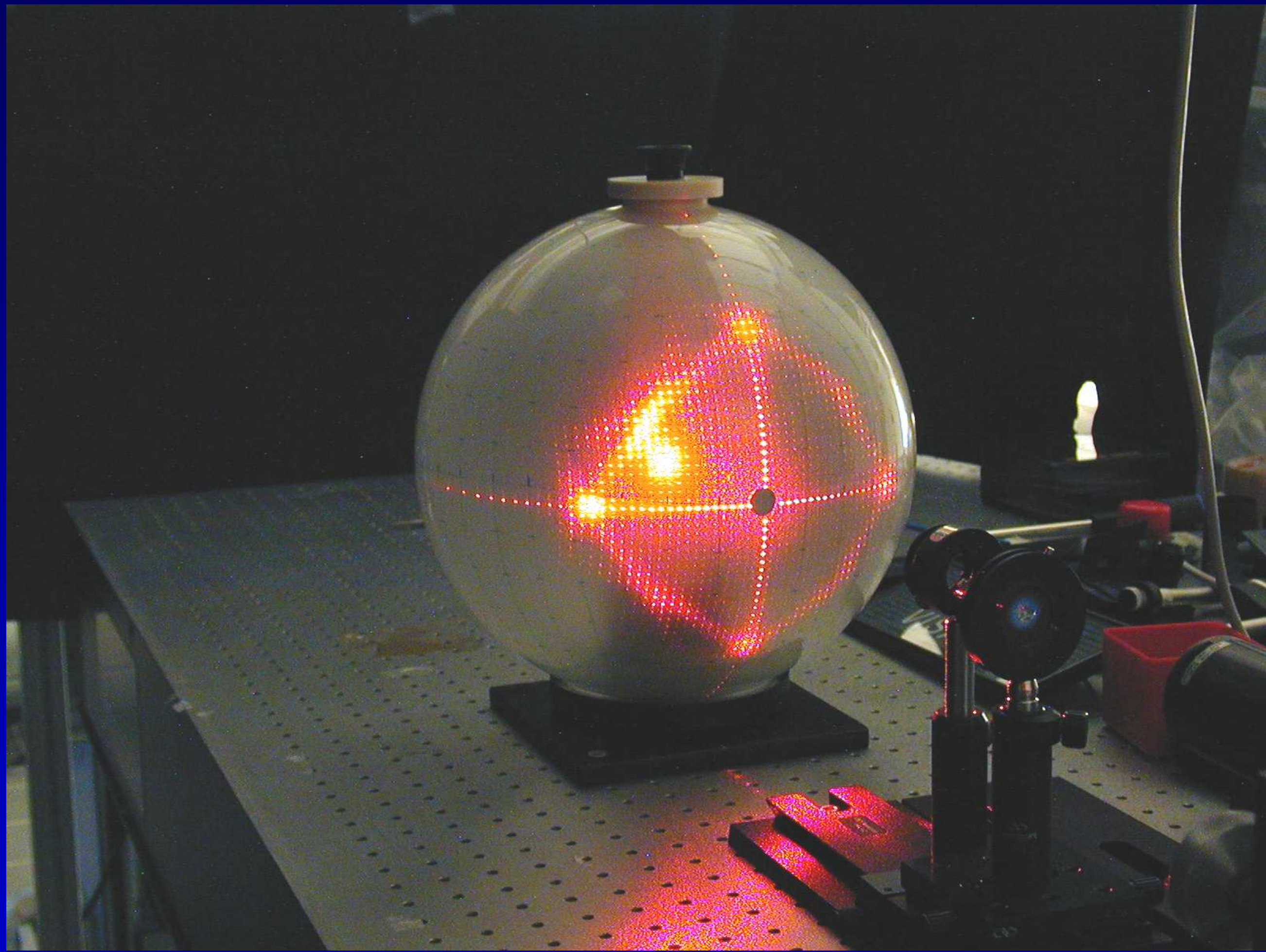
Map of light intensity backscattered by a porous-Si sample (Laser light λ=633 nm; 0° incidence).

VISUALIZING GLOBE



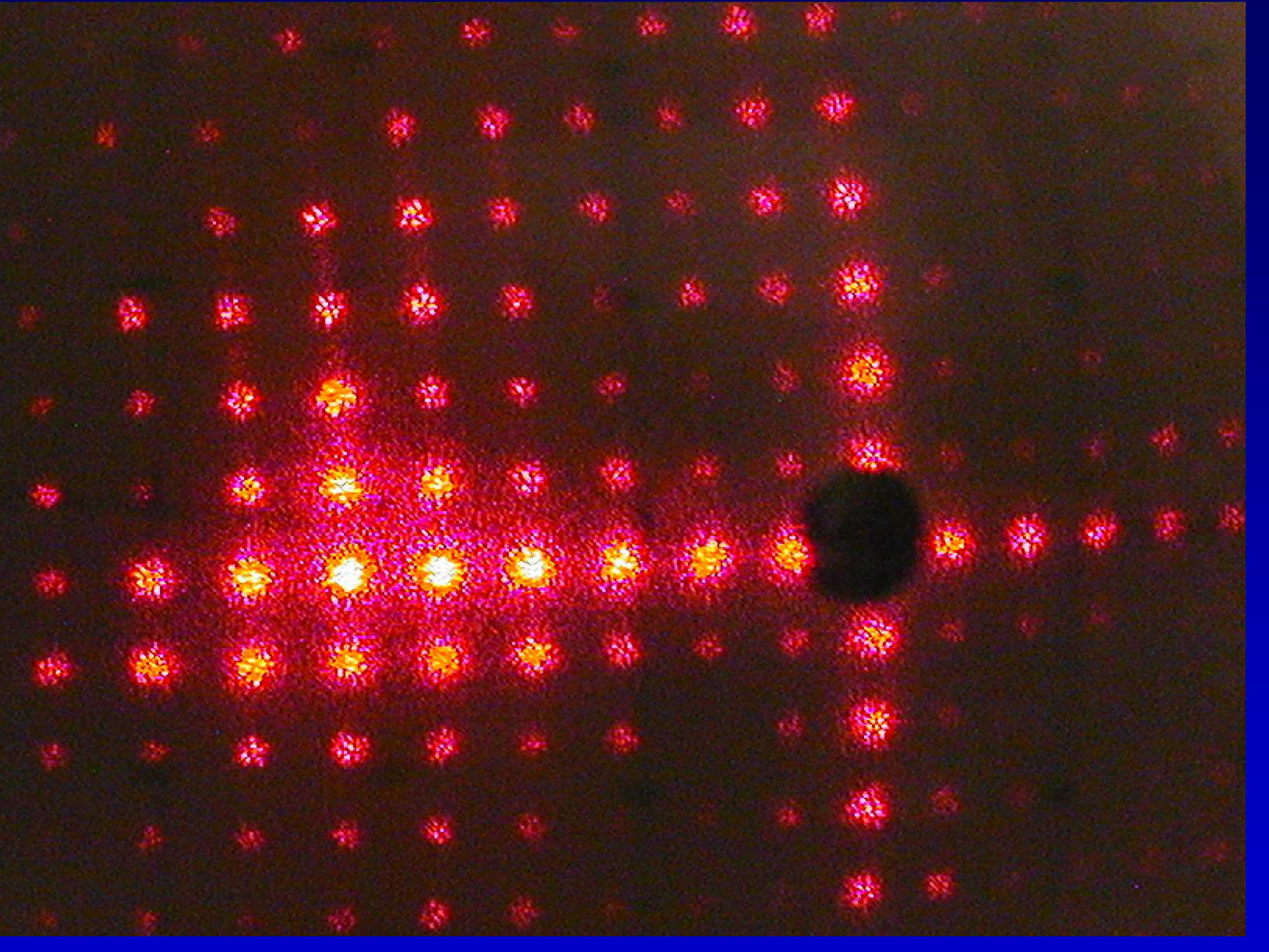
The plastic globe is internally sand-blasted in order to scatter, and then visualize, the light backscattered by the sample.

VISUALIZING GLOBE



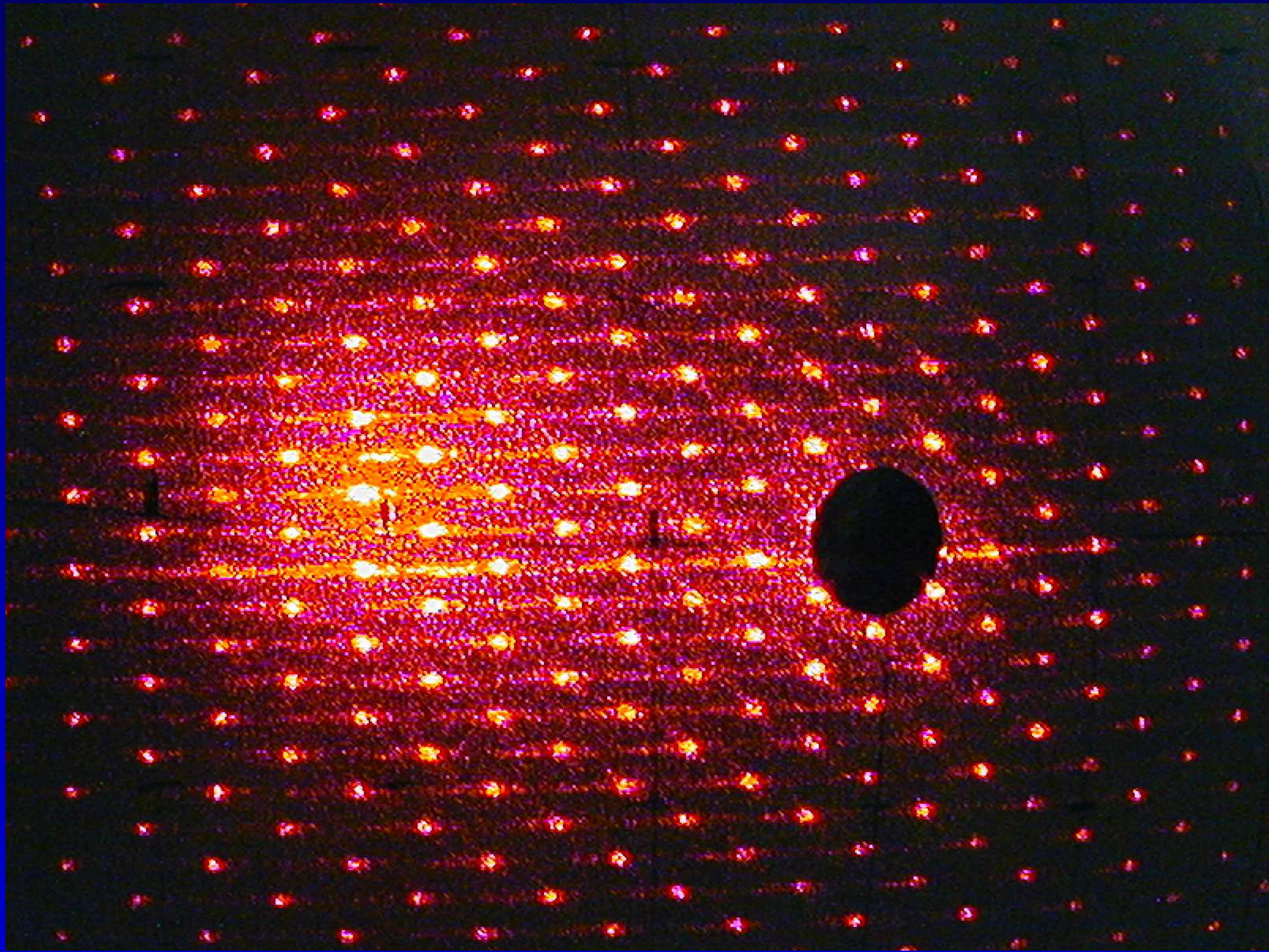
The sand-blasted globe shows the light backscattering figure produced by a solar cell textured by inverted pyramids (Fraunhofer).

VISUALIZING GLOBE



Particular of the light diffraction figure (LDF) produced by inverted pyramids texture.

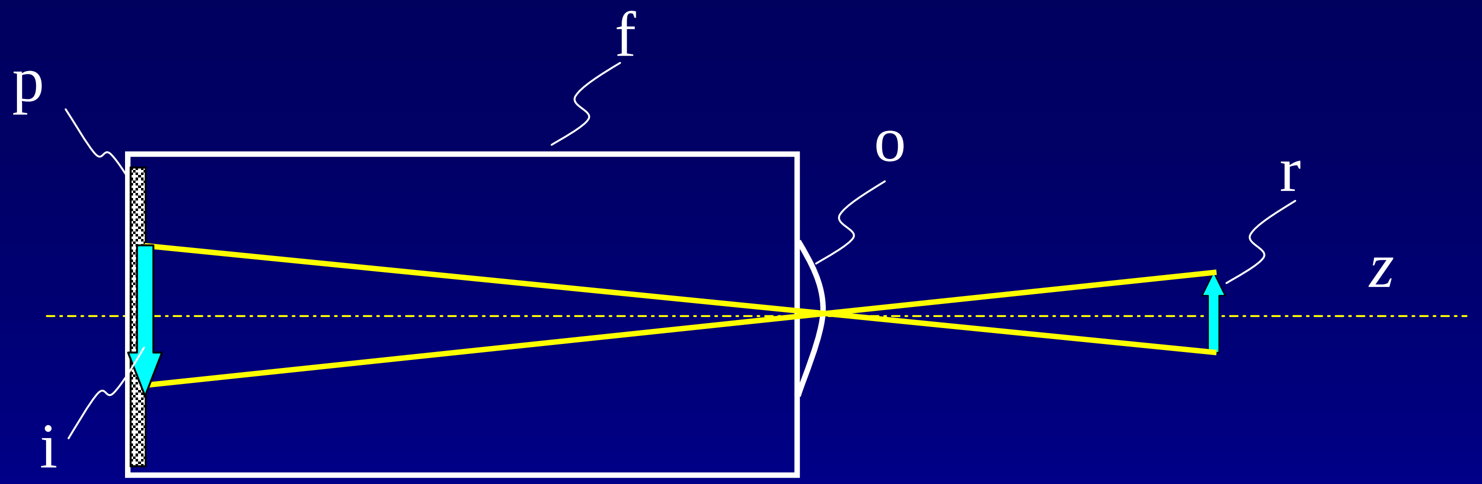
VISUALIZING GLOBE



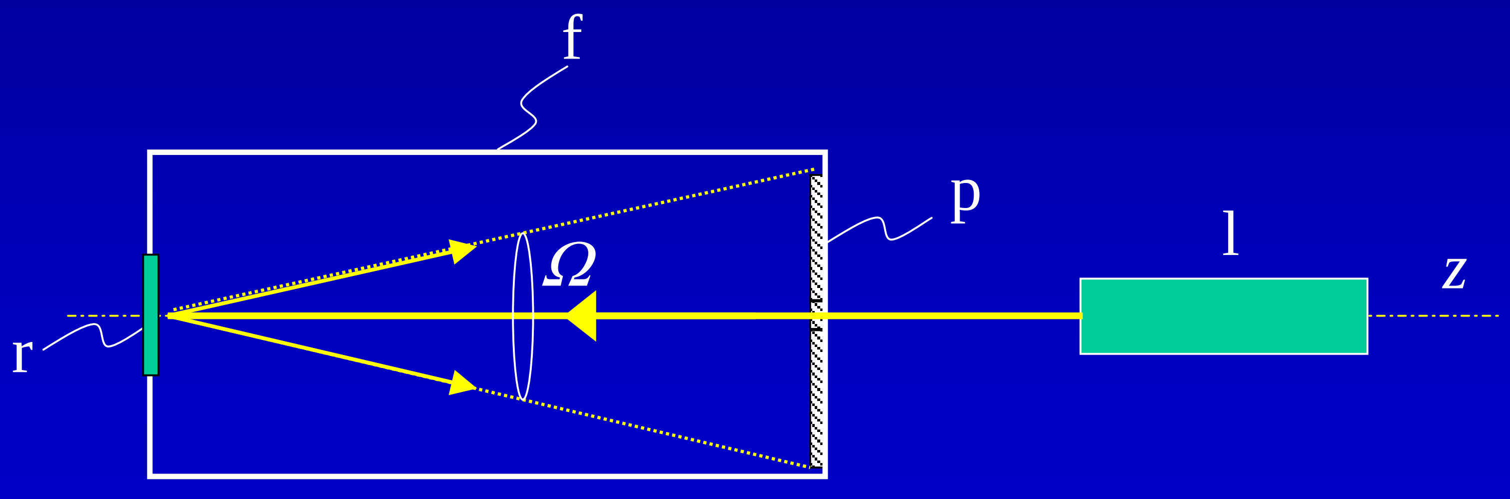
Particular of the light diffraction figure (LDF) produced by a honeycomb textured cell (UNSW).

PHOTOCAMERA FOR RECORDING

THE BACKSCATTERED LIGHT



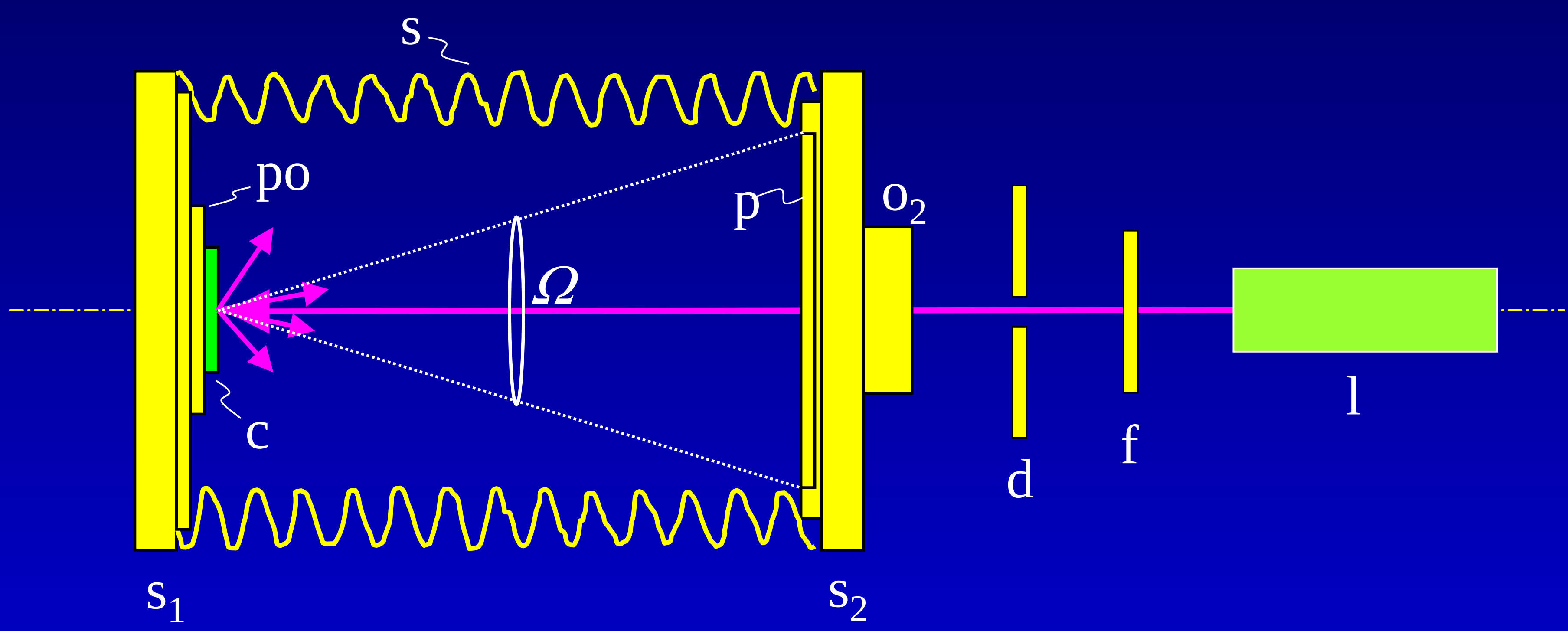
Normal (refraction) photocamera



CARDIFF (scattering) photocamera

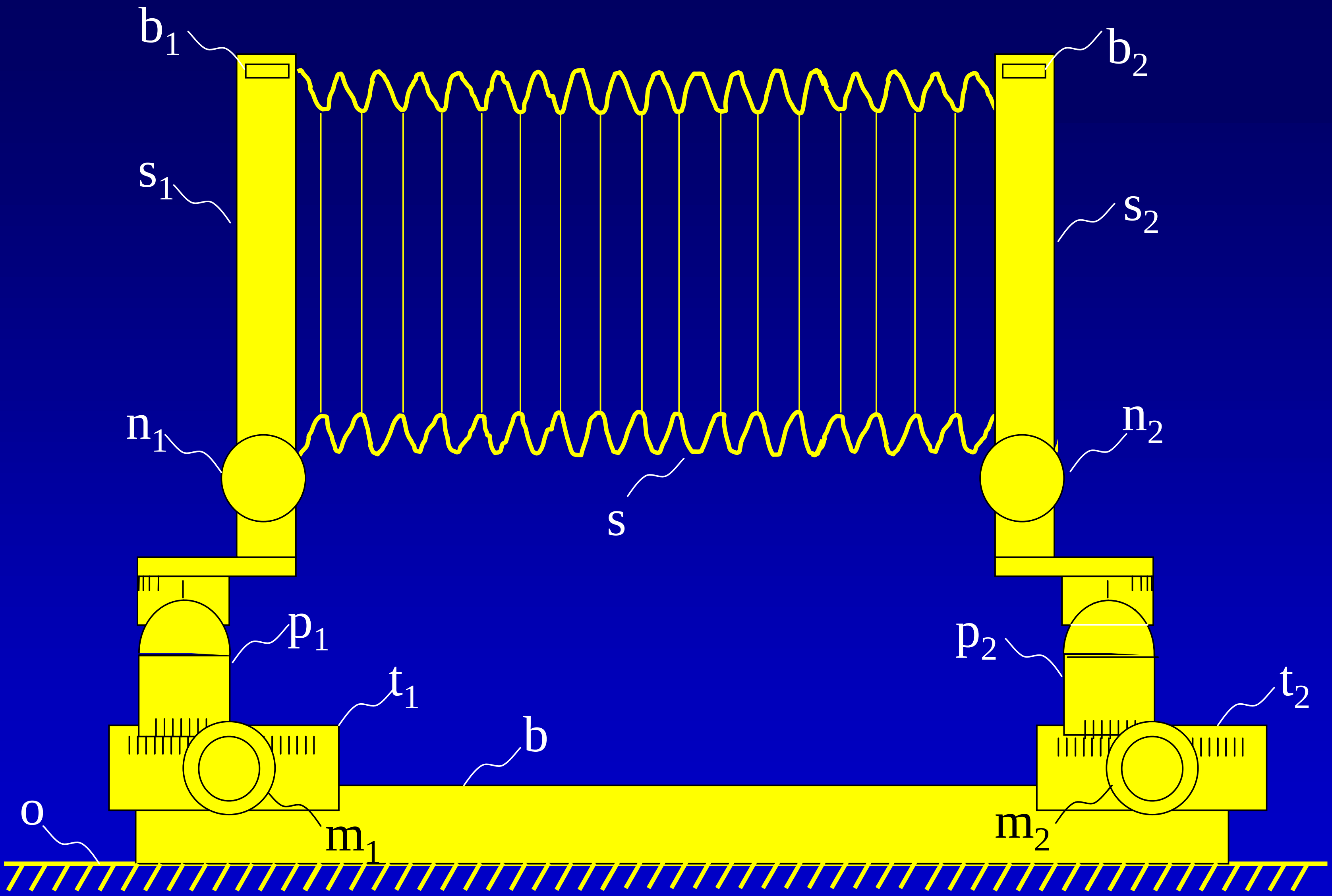
PHOTOCAMERA CARDIFF (patented)

(CAmera for Recording DIFFused and DIFFracted light



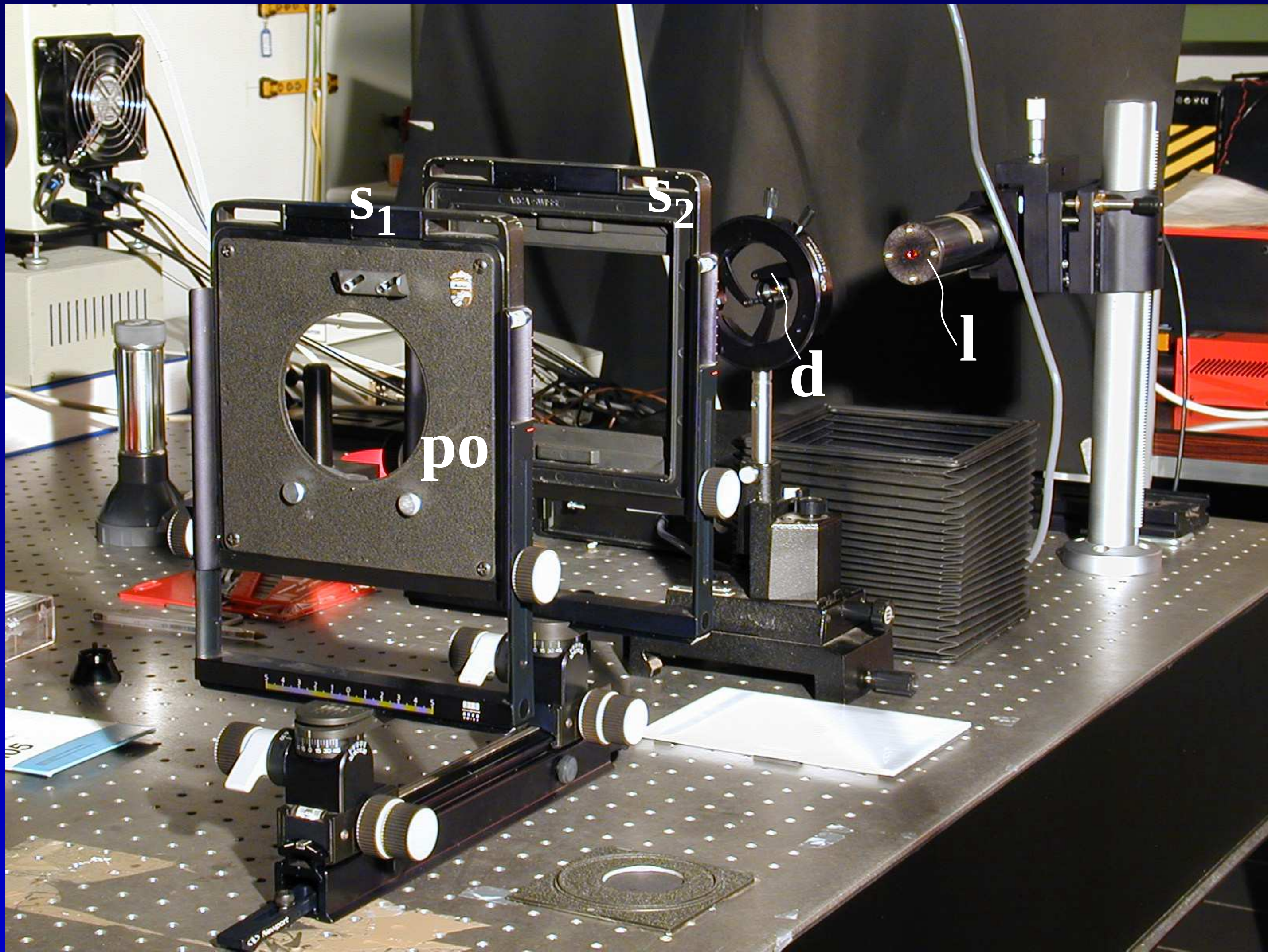
Schematics of the CARDIFF apparatus for recording light backscattered from small textured photovoltaic samples.

PHOTOCAMERA CARDIFF



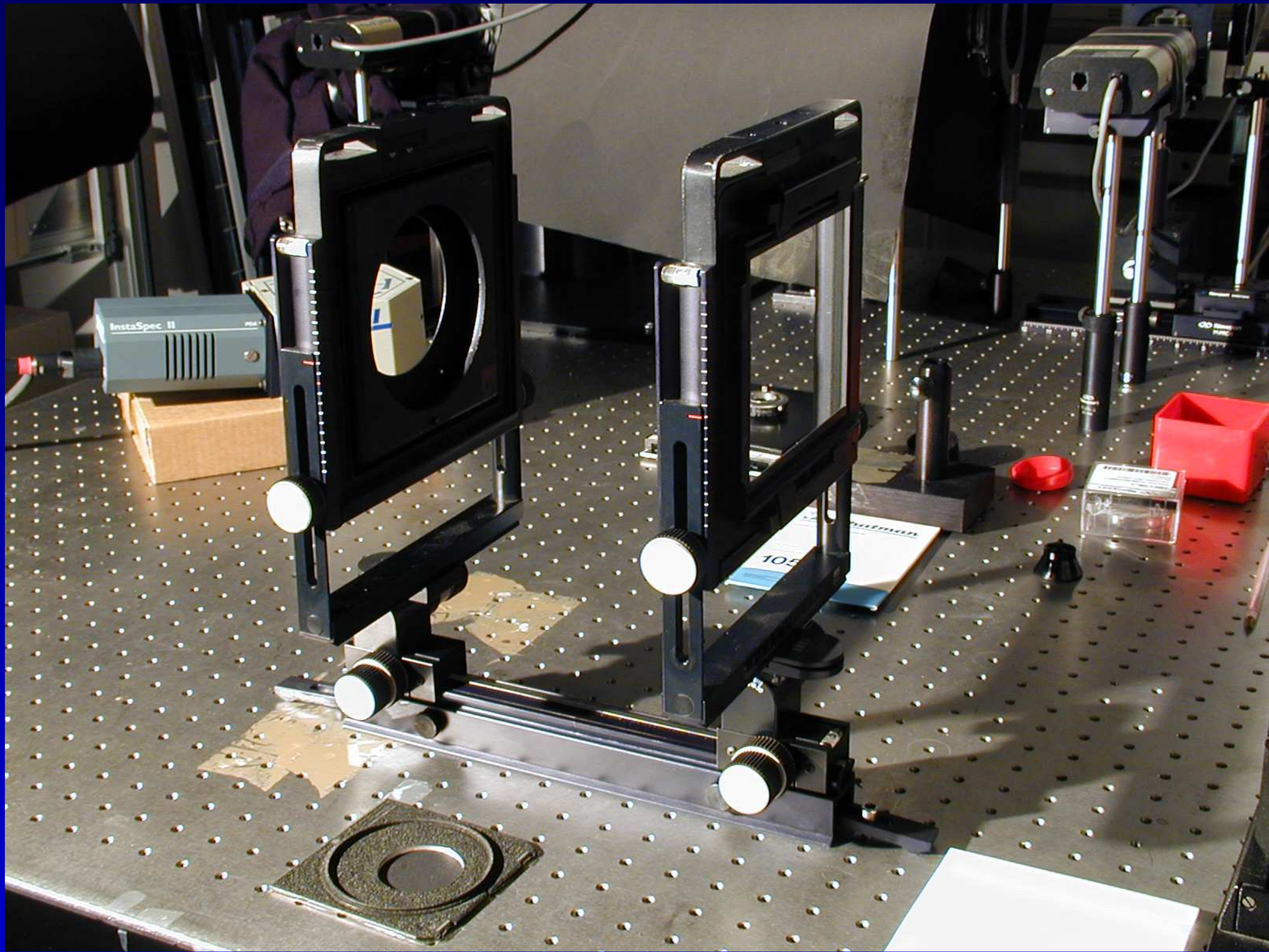
Drawing of the photocamera CARDIFF mounted on a rail,
and fixed on an optical bench.

PHOTOCAMERA CARDIFF



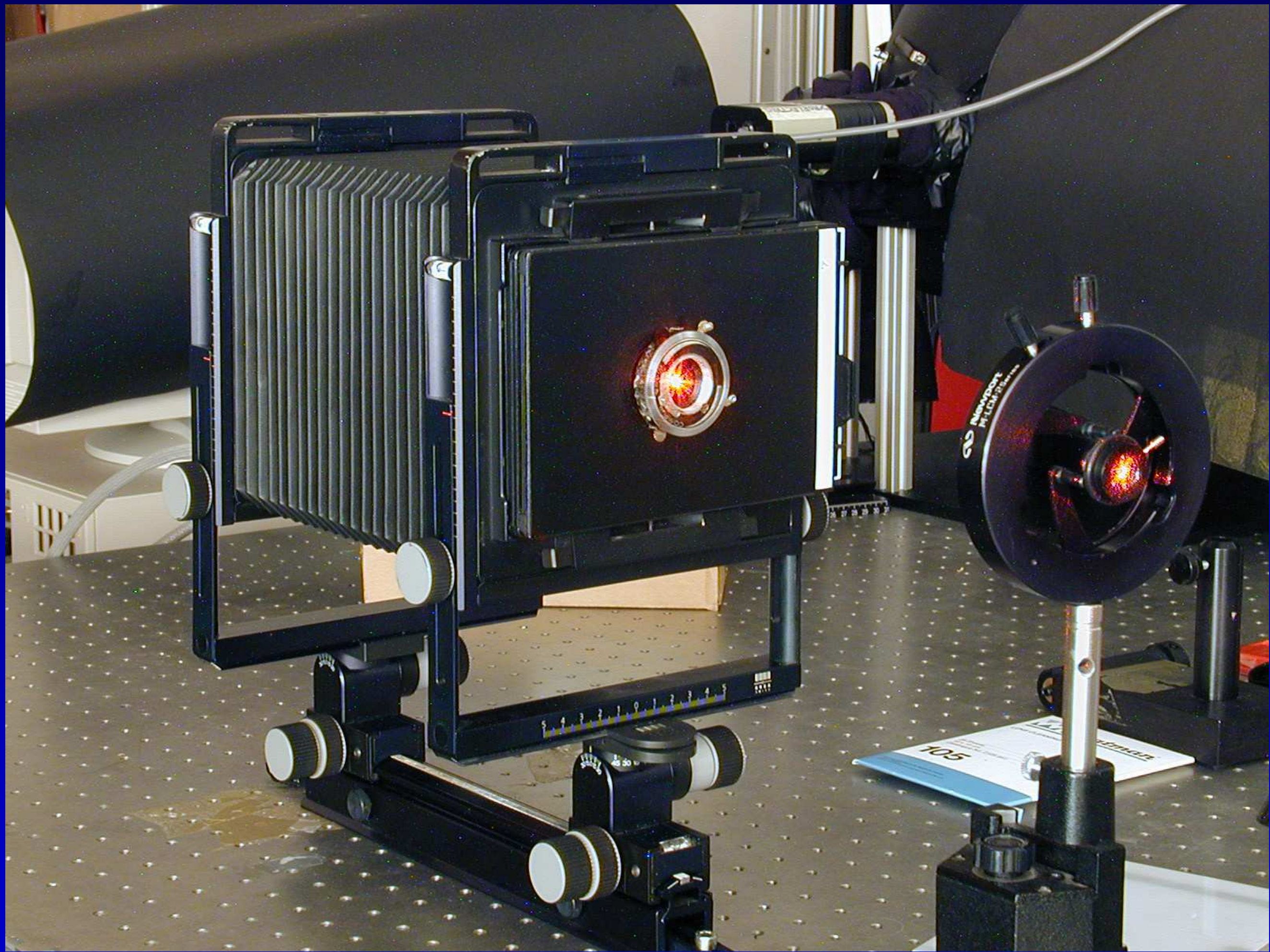
The CARDIFF photocamera has been realized in collaboration with the Studio Granata (Naples).

PHOTOCAMERA CARDIFF



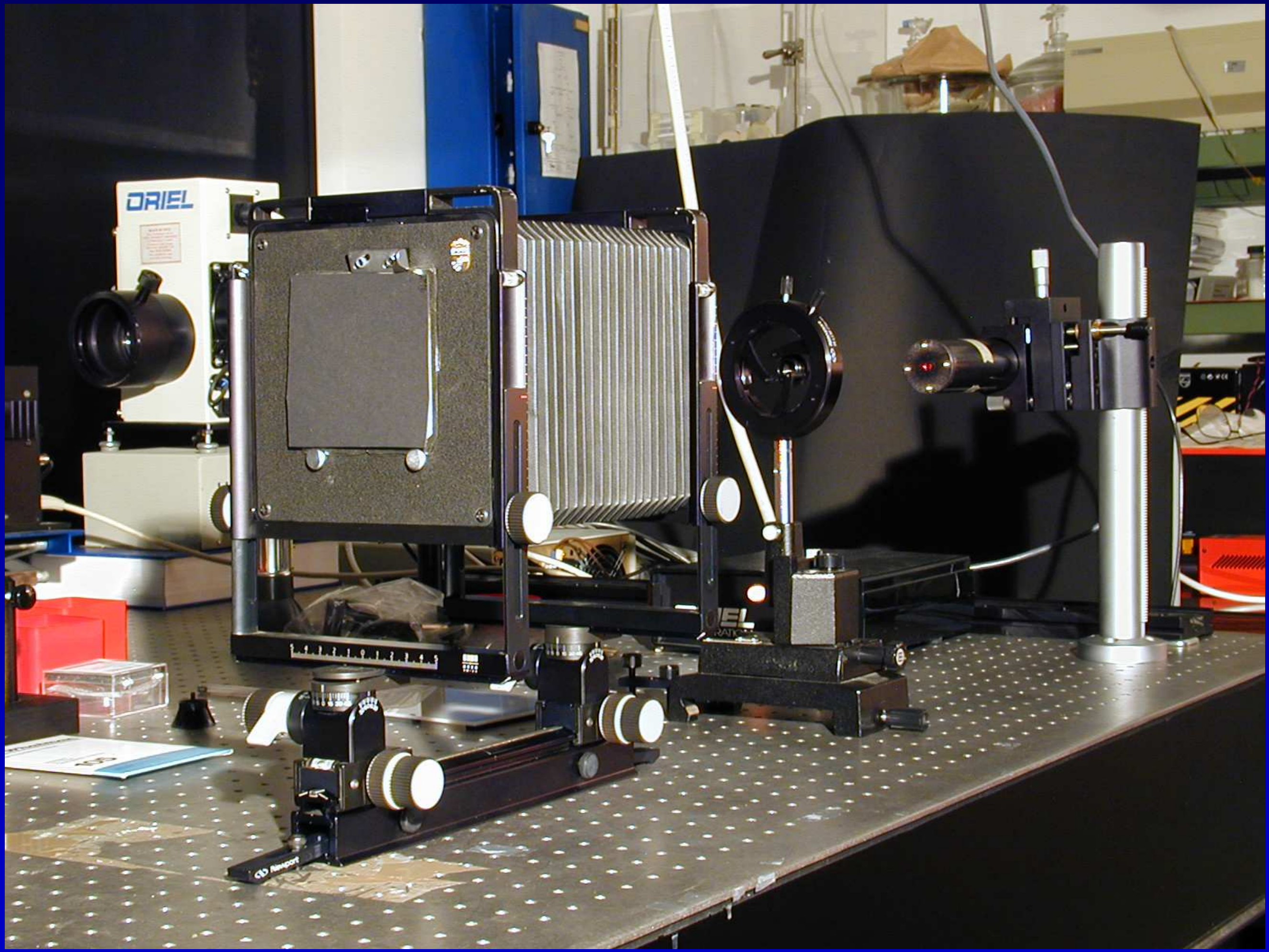
The photocamera CARDIFF is shown open.

PHOTOCAMERA CARDIFF



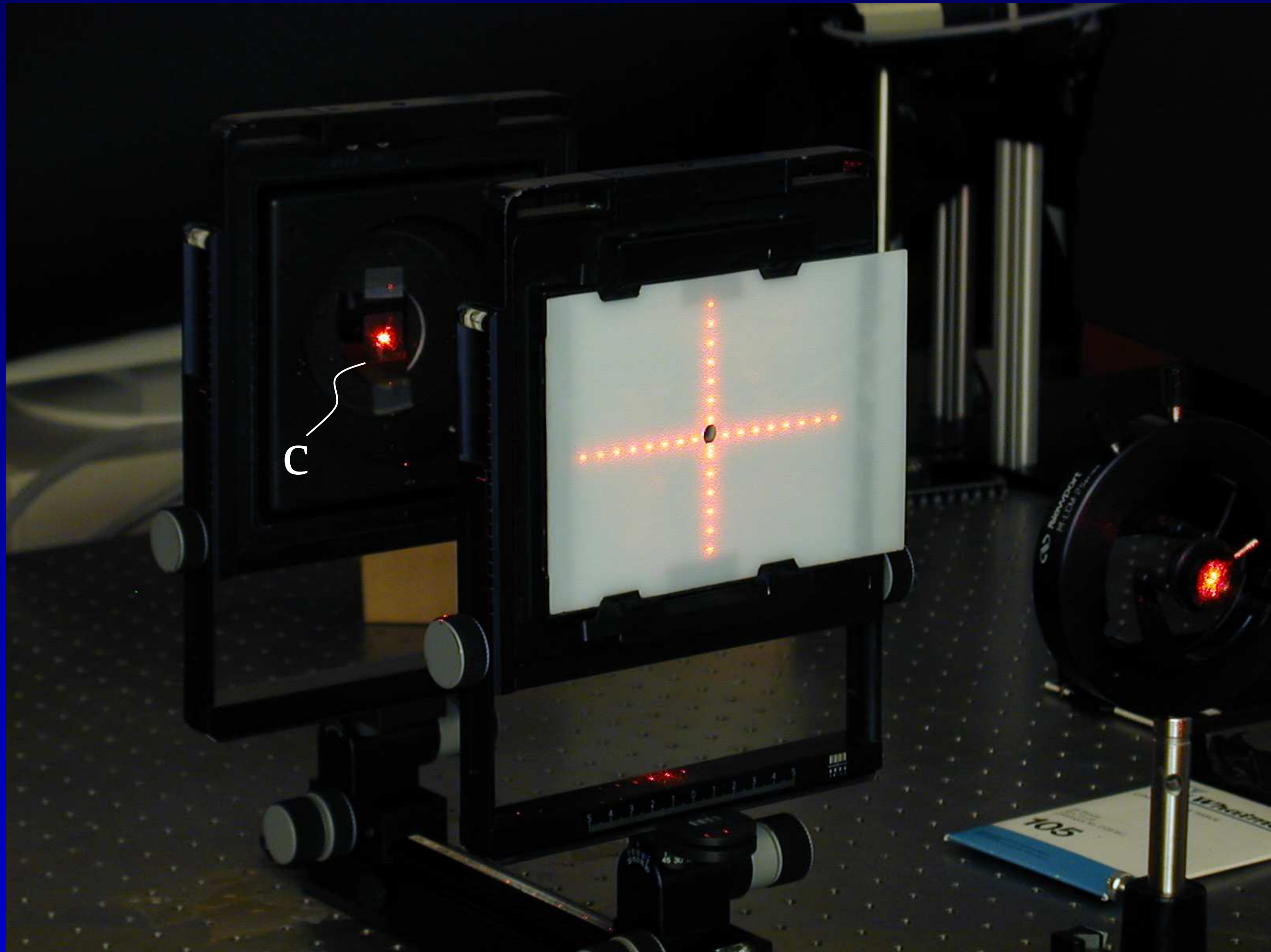
Photocamera CARDIFF assembled for measurements (front side).

PHOTOCAMERA CARDIFF



Photocamera CARDIFF assembled for measurements (back side).

PHOTOCAMERA CARDIFF



Alignement of the photocamera components by using a frosted glass screen.
It is shown the light diffraction figure (LDF) produced by a PERL cell.

CHARACTERIZATION OF SMALL TEXTURED SAMPLES

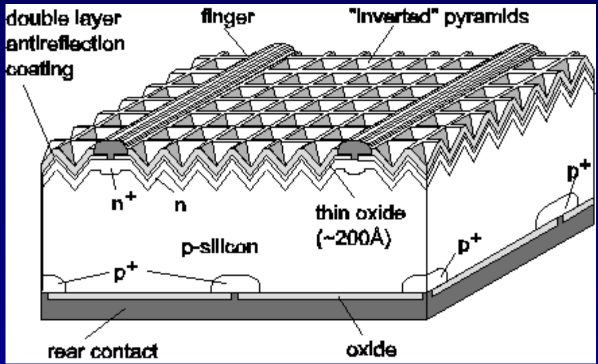
Conditions:

He-Ne laser $\lambda = 632.8$ nm, $P = 25$ mW;
Sample-plate distance: $d = 170$ mm;
Exposed area: 120 x 95 mm;
Exposition time: $t_0 \approx 100$ msec;
Use of neutral filter;
Photographic plate: panchromatic paper ($\lambda > 580$ nm);
orthochromatic paper ($\lambda = 400\text{-}580$ nm).

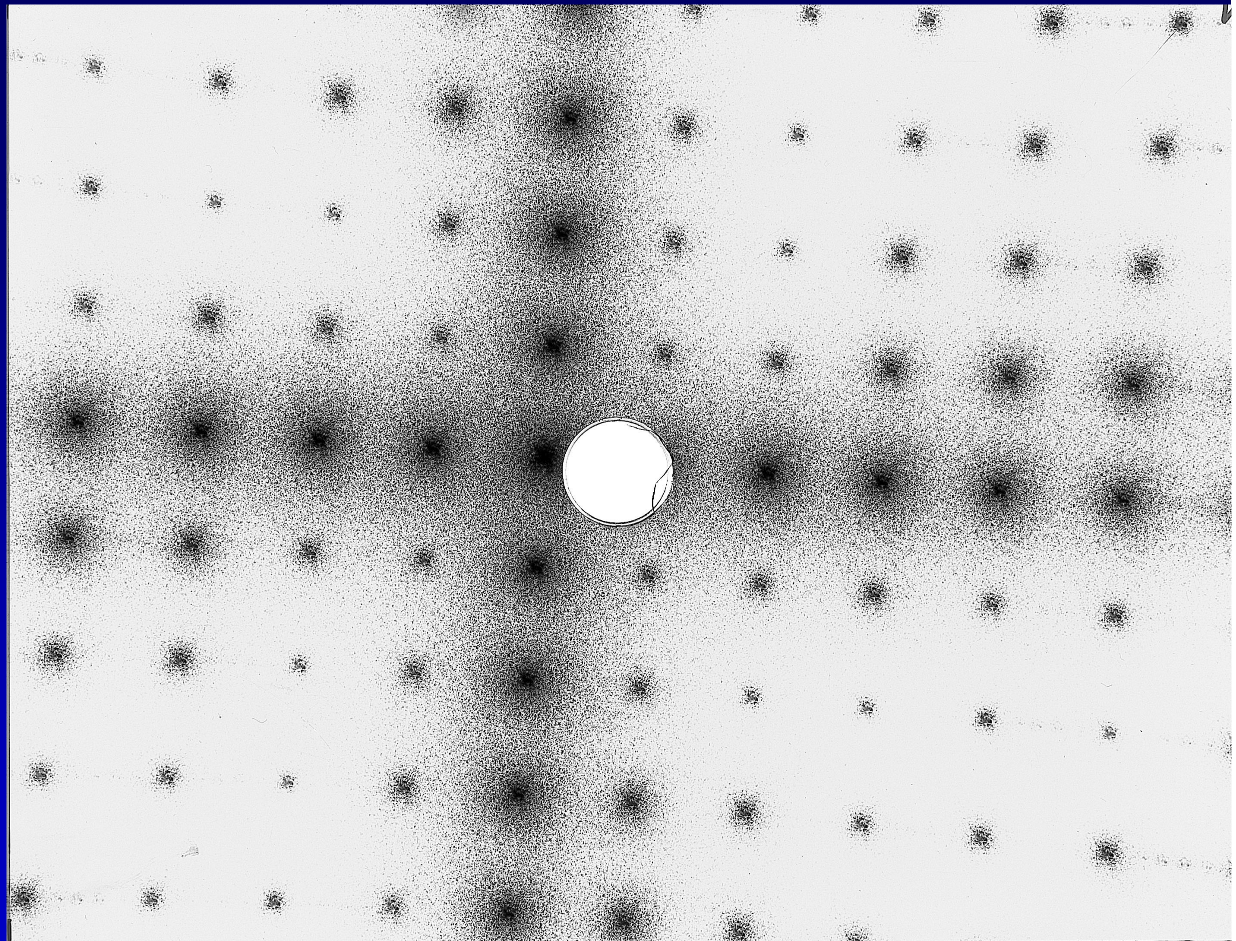
N°	Sample	d(mm)	Texture	Notes
1	**PERL**	**170**	**Inverted pyramids**	**Beam on grid**
2	**“**	**“**	**“**	**Beam on Si**
3	**“**	**“**	**“**	**Beam on grid**
4	**PYR**	**“**	**“**	**Beam on Si**
5	**HC**	**“**	**Hemispherical wells**	**Beam on Si**
6	**“**	**“**	**“**	**Beam on grid**
7	**“**	**“**	**“**	**“**
8	**m-Si**	**“**	**Right upright pyramids**	**“**
9	**p-Si**	**“**	**nanoporosity**	**Beam on Si**
10	**PERL module**	**“**	**Inverted pyramids**	**Beam on grid**
11	**“**	**“**	**“**	**“**

Table of characterized samples.

INVERTED PYRAMIDS TEXTURE

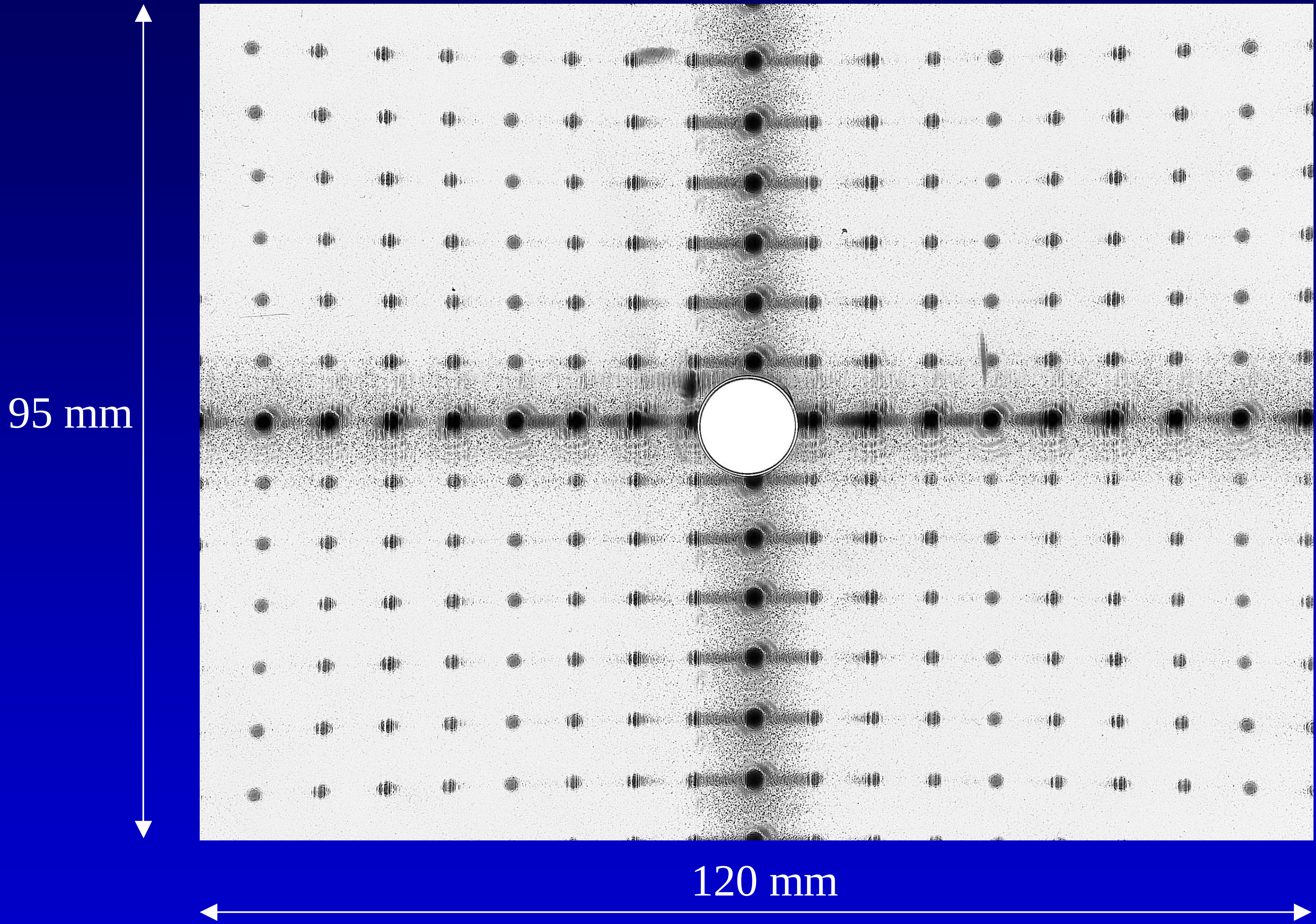


Mono-Si cell (PERL)
from UNSW
(η = 24.4 %).
Texture: square lattice of inverted pyramids, realized by photolitography with *anisotropic* etching of the (100) Si surface.



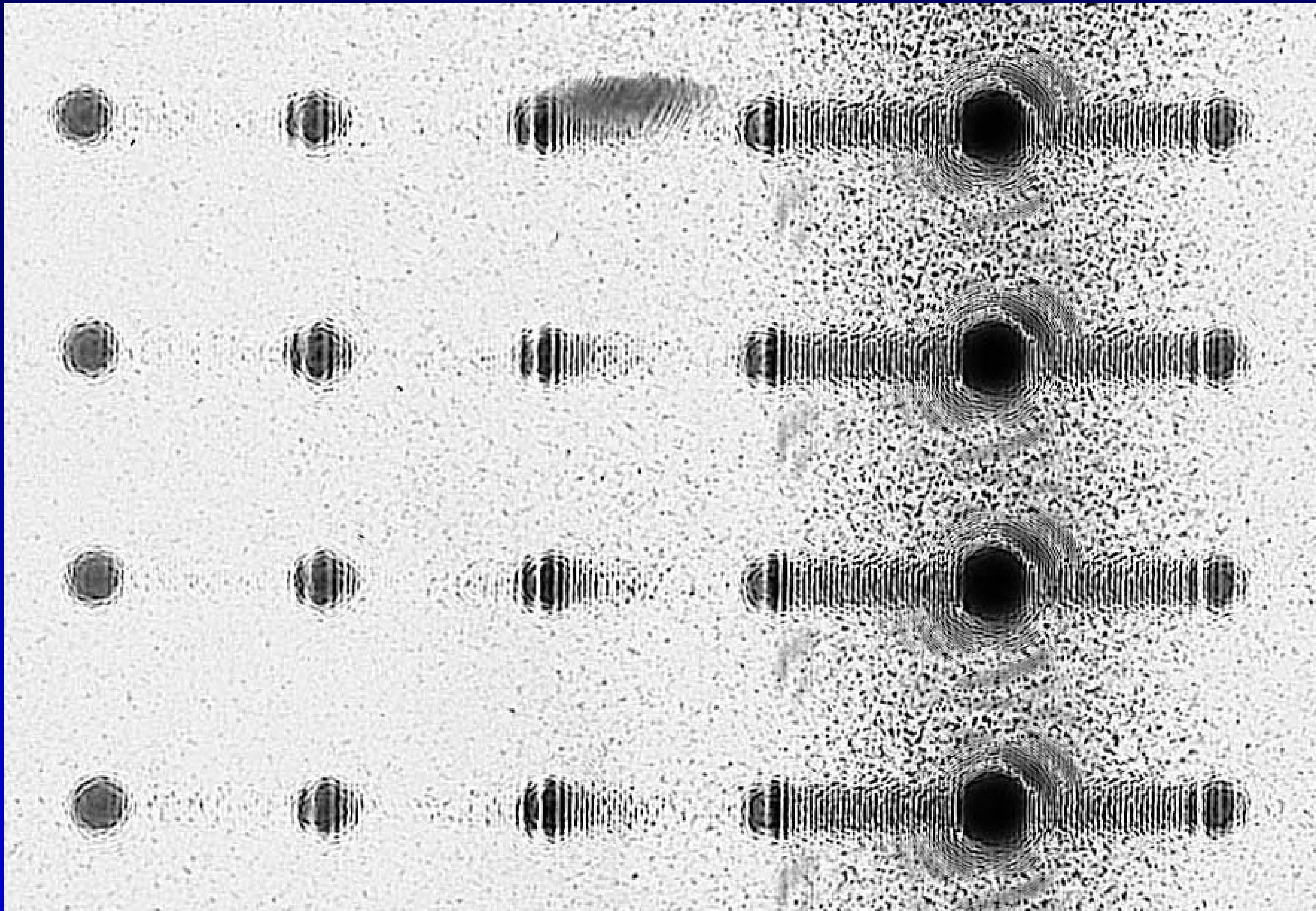
Negative of the light diffraction figure (LDF).
The central hole on the plate is for the passage of the incident light beam.

INVERTED PYRAMIDS TEXTURE



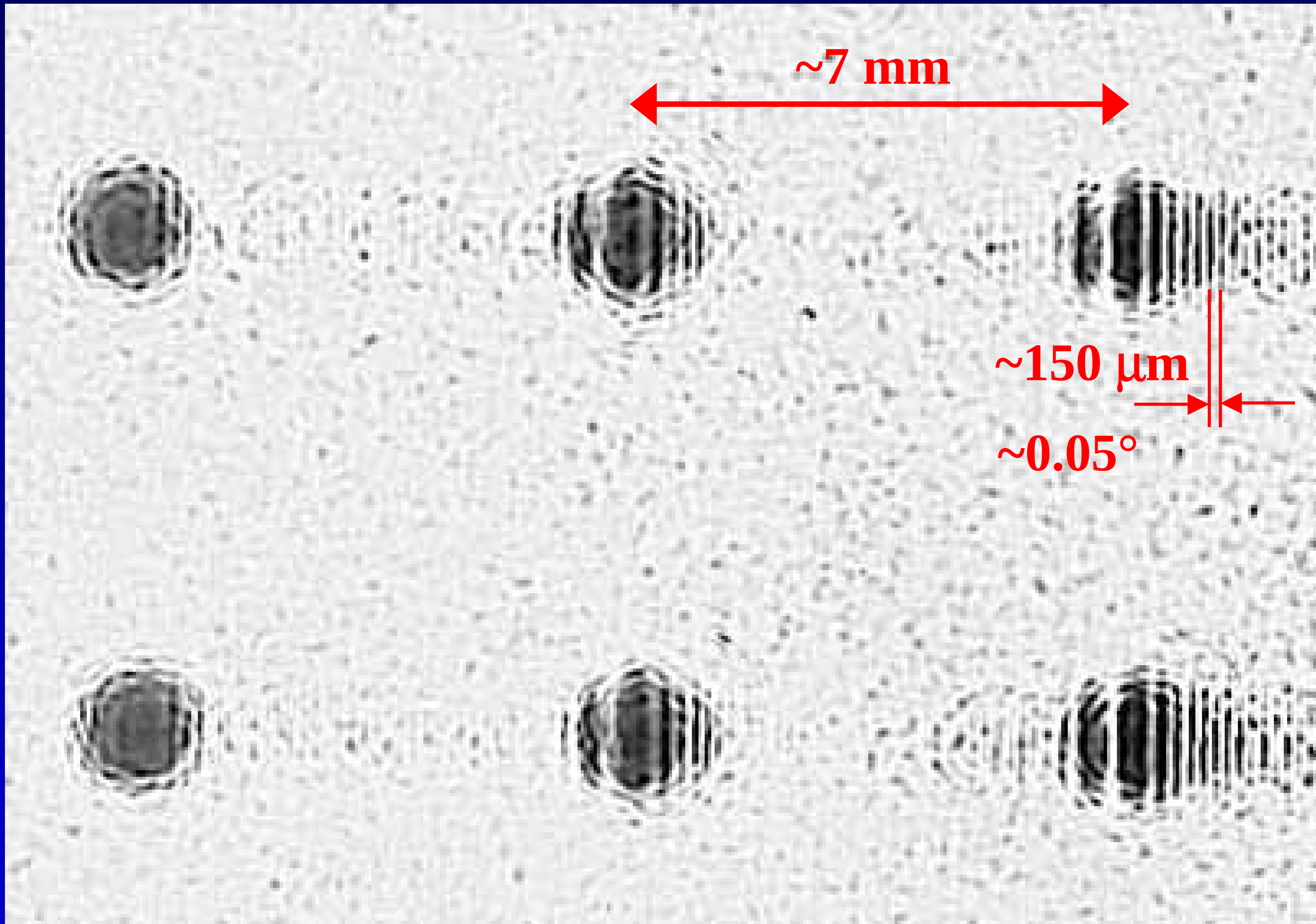
Light Diffraction Figure (LDF) of a PERL cell.

INVERTED PYRAMIDS TEXTURE



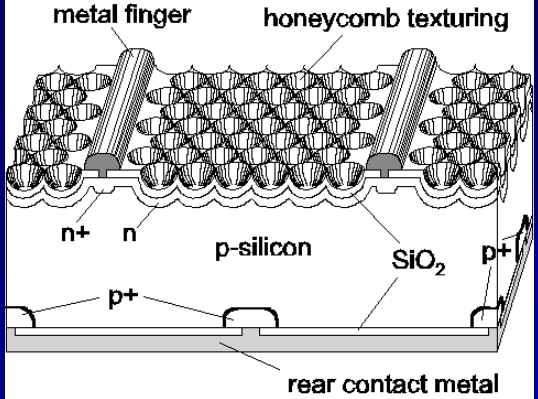
Particular of the LDF of a PERL cell

INVERTED PYRAMIDS TEXTURE

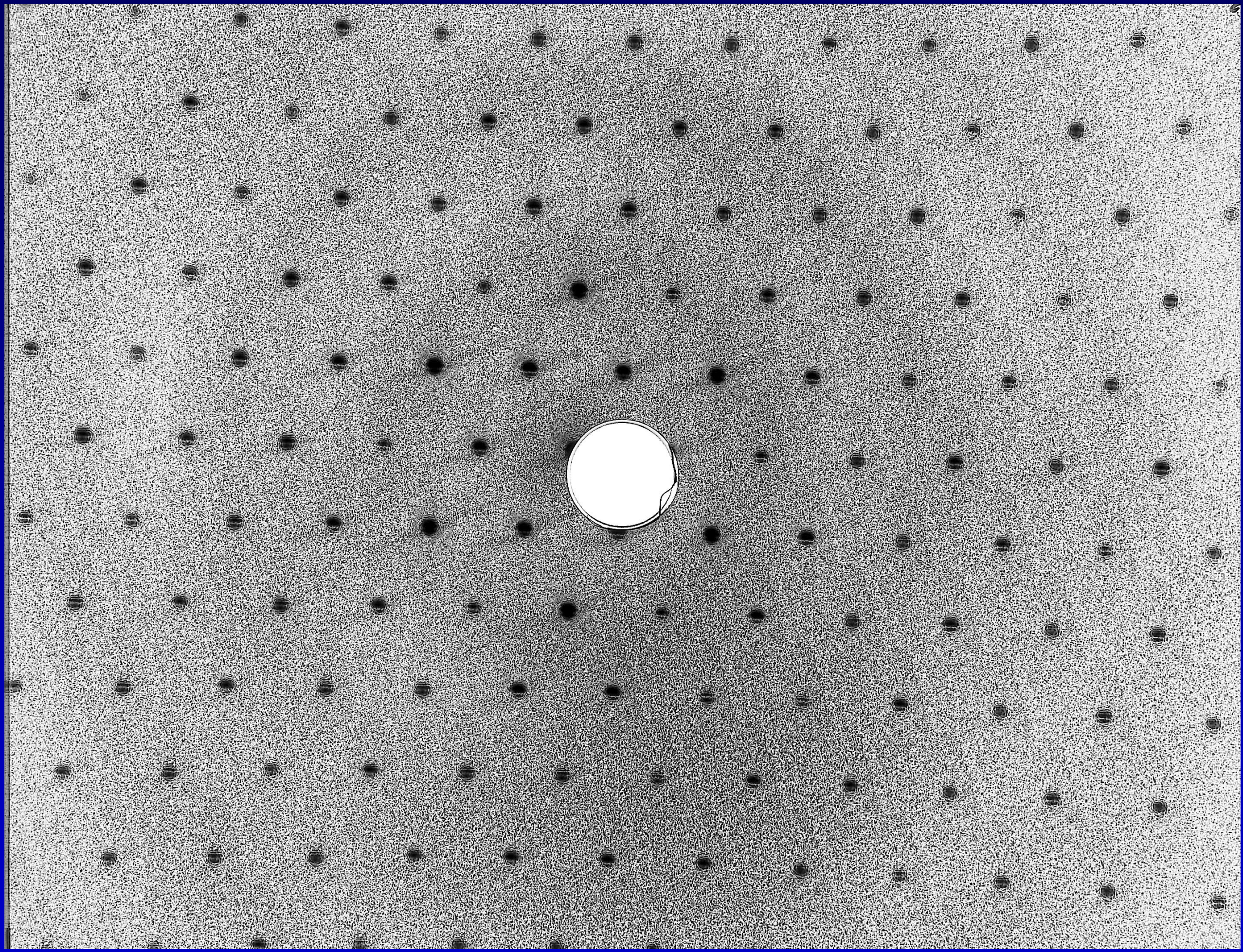


Particular of the LDF of a PERL cell

HONEYCOMB TEXTURE



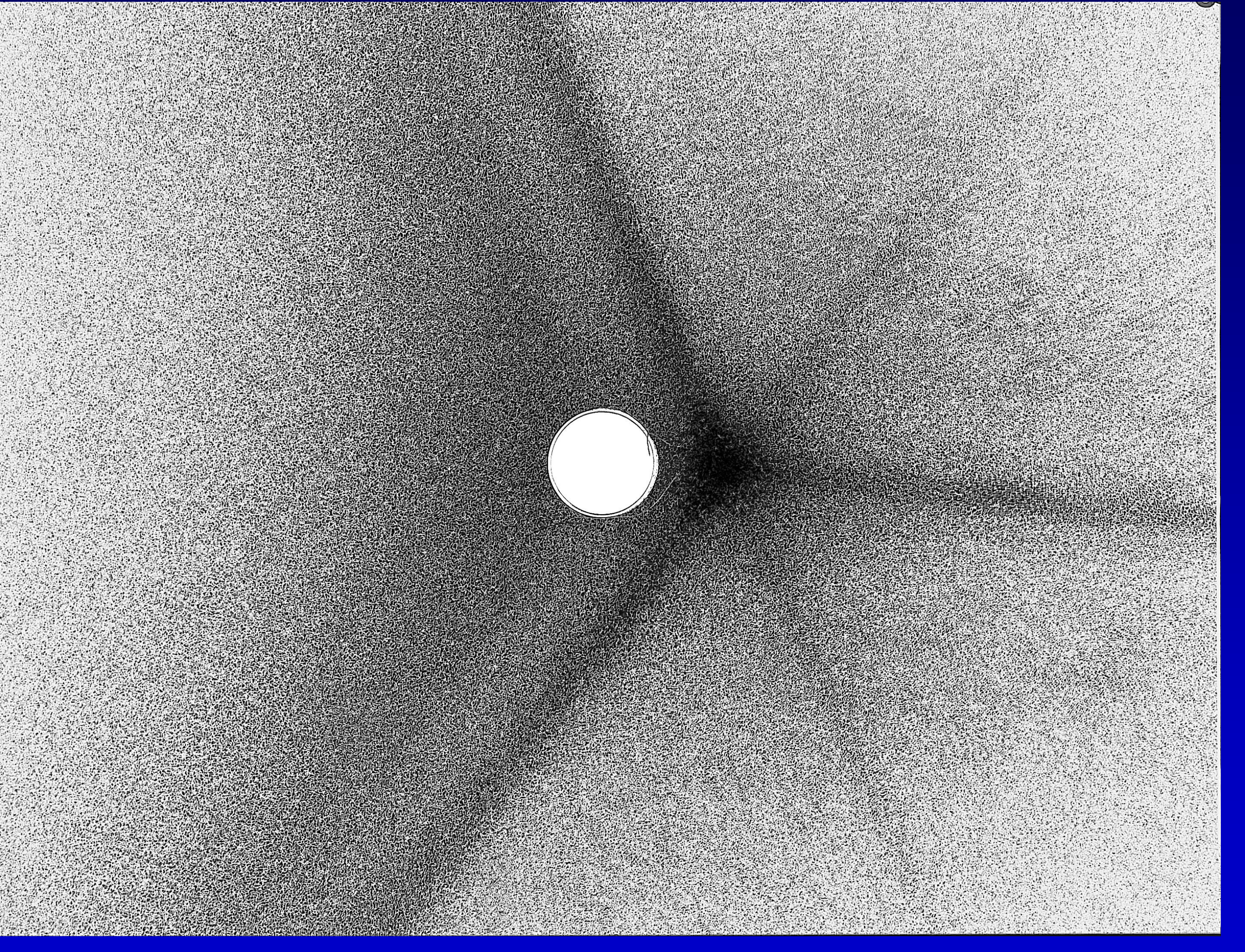
Multi-Si cell from UNSW (η = 19.8 %). Texture: honeycomb lattice of hemispherical wells, realized by photolitography with *isotropic* etching of the multi-Si surface.



Negative of the light diffraction figure (LDF).

PHOTOCAMERA CARDIFF

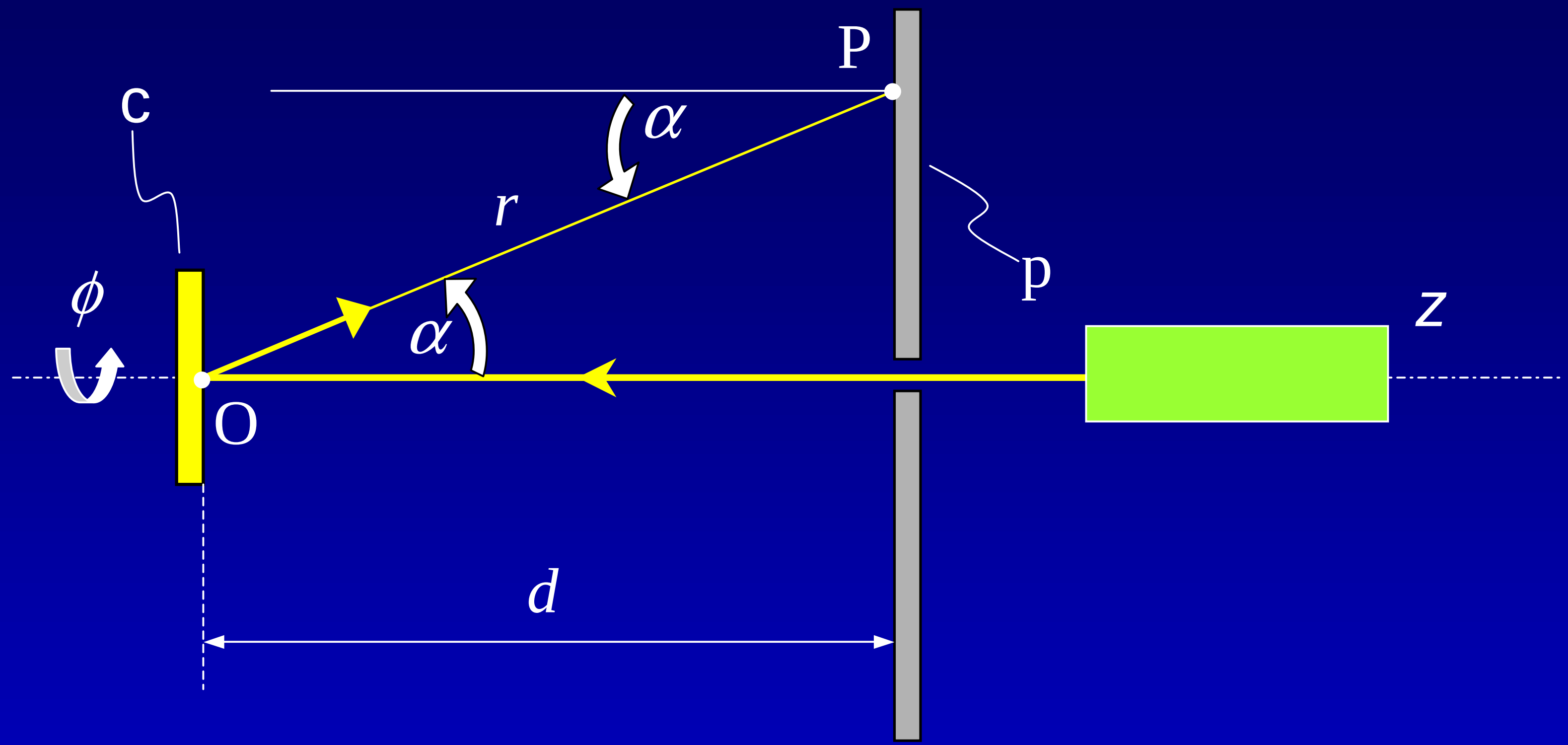
Mono-Si cell from Eurosolare (η = %). Texture: random upright pyramids,realized by *anisotropic* etching of the (100) Si surface.



Negative of the light diffraction figure (LDF).

ANALYSIS OF THE SCATTERED LIGHT

(plane geometry)



$$G_{abs}(d,\alpha,\lambda) \propto G_{scat}^{\perp} \cdot \frac{1}{r^2} \cdot \cos\alpha\left[1 - R(\alpha,\lambda)\right]$$

$$G_{abs}(d,\alpha,\lambda) \propto G_{scat}^{\perp} \cdot \frac{1}{d^2} \cdot \cos^3\alpha\left[1 - R(\alpha,\lambda)\right]$$

ANALYSIS OF THE SCATTERED LIGHT
(plane geometry)

$$G_{abs}(d,\alpha,\lambda,t) \propto G_{scat}^{\perp} \cdot \frac{1}{d^2} \cdot \cos^3 \alpha \left[1 - R(\alpha,\lambda,t)\right]$$

$$0 \le t \le t_0 \quad t_0 = exposition\ \ time$$

$$\overline{G}_{abs}(d,\alpha,\lambda,t) \propto G_{scat}^{\perp} \cdot \frac{1}{d^2} \cdot \cos^3 \alpha \left[1 - \overline{R}(\alpha,\lambda,t_0)\right]$$

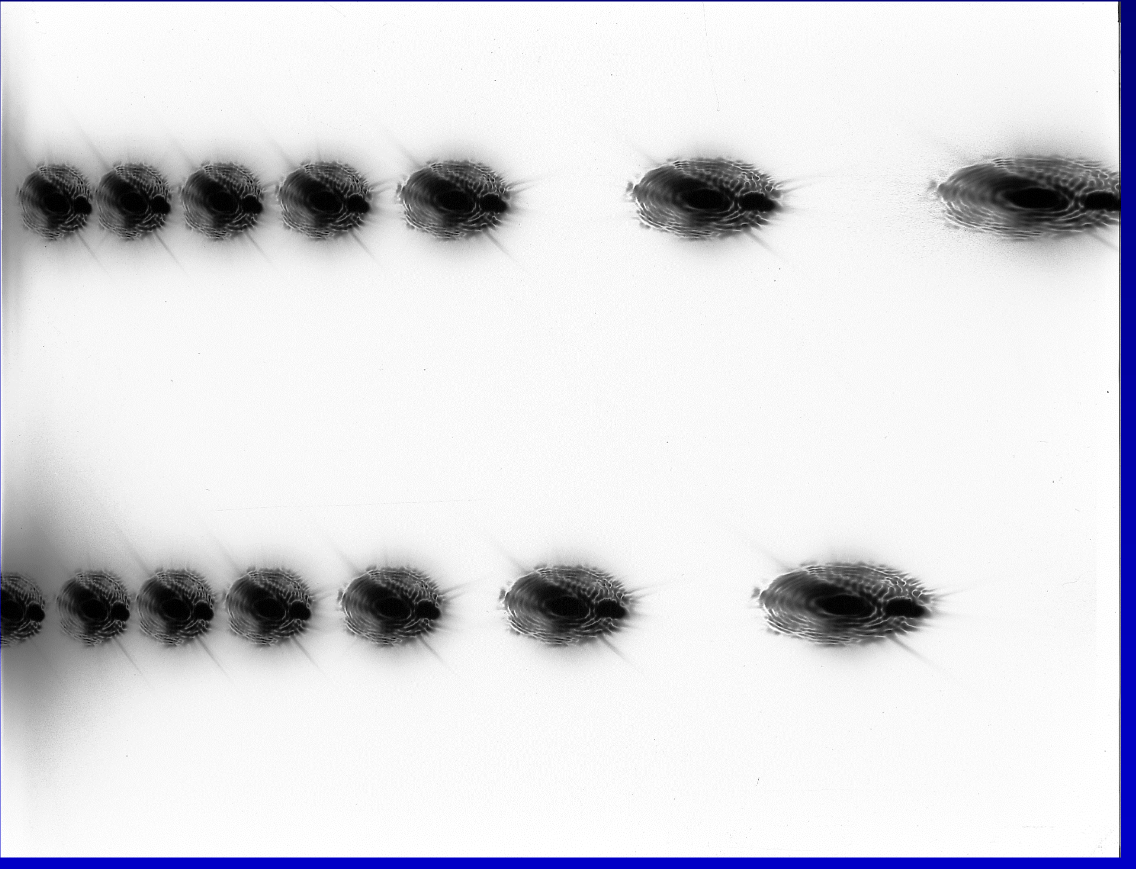
At a first approximation, the plate reflectivity can be assumed constant with respect to α *:*

$$\overline{G}_{abs}(d,\alpha,\lambda,t_0) \propto G_{scat}^{\perp} \cdot \frac{1}{d^2} \cdot \cos^3 \alpha \left[1 - \overline{R}(\lambda,t_0)\right]$$

ENEA

ANALYSIS OF THE SCATTERED LIGH
(plane geometry)

Work is in progress in order to measure the reflectance properties of the photographic plate as a function of λ, α and t_0.



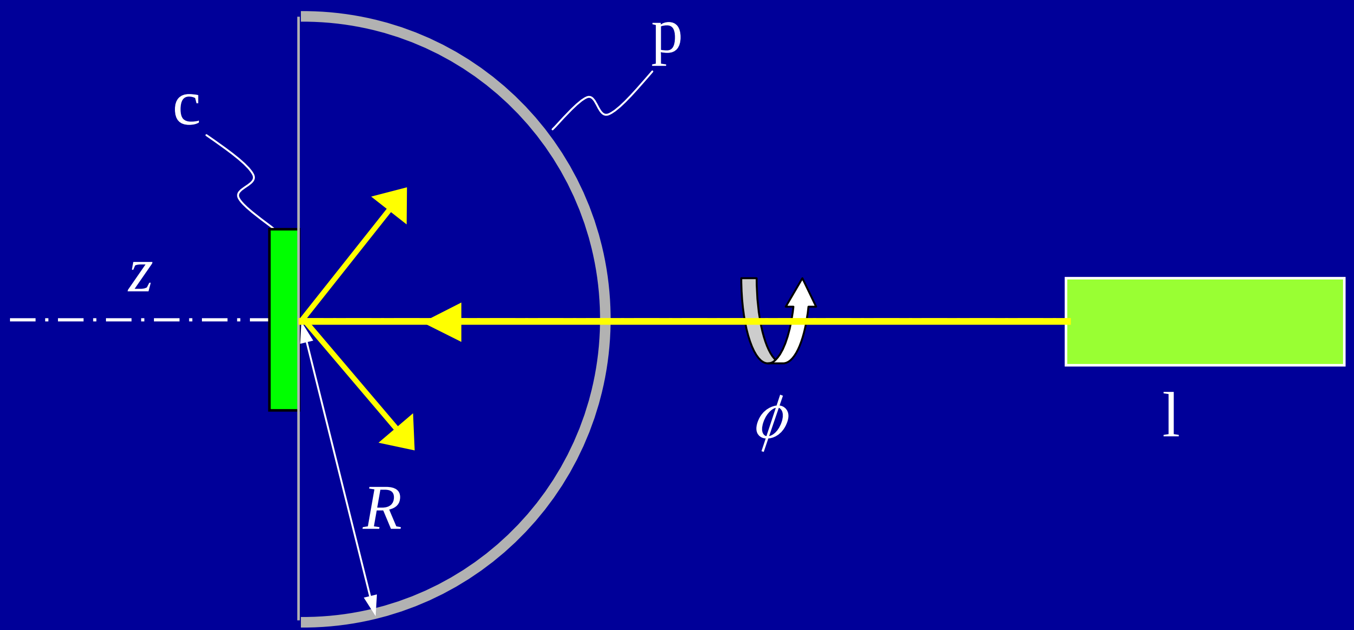
Example of a test performed to study the variation of contrast as function of the angle of incidence of a 633 nm laser beam.

OTHER DESIGNS OF THE

CARDIFF PHOTOCAMERA

CYLINDRICAL PHOTOCAMERA

In order to reduce the effect of both distance and angle of incidence on the plate contrast, the photocamera can be designed with a *cylindrical shape*:



The cylindrical camera allows to record light scattered along the equatorial plane between -90° and +90°, at a constant distance *R*, and at a constant angle of incidence of 90°.

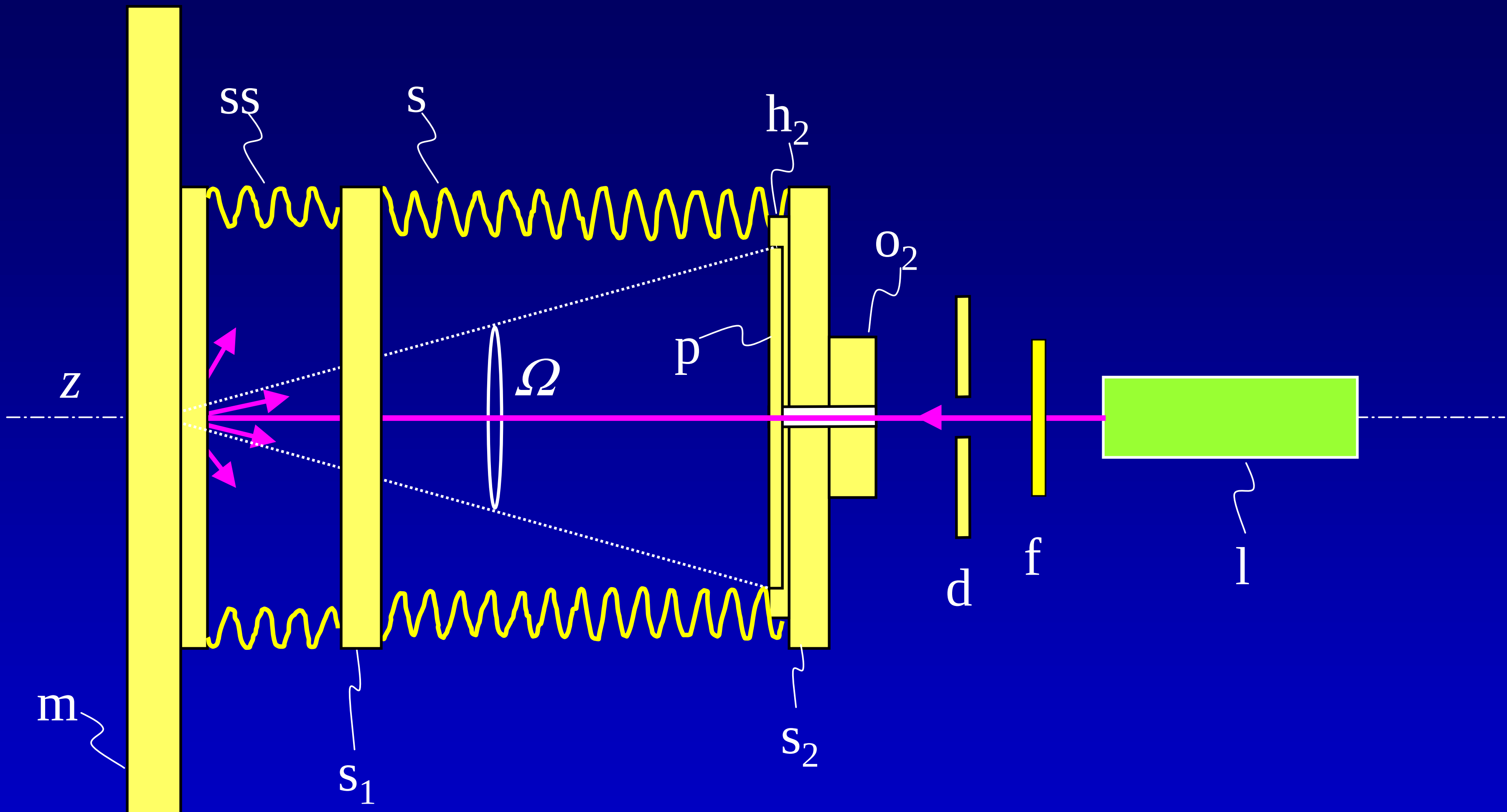
ANALYSIS OF THE SCATTERED LIGHT
(cylindrical geometry)

$$G_{abs}(d,\lambda,t) \propto G_{scat}^{\perp} \cdot \frac{1}{R^2} \cdot \left[1 - R(90°,\lambda,t)\right]$$

$$0 \le t \le t_0 \qquad t_0 = exposition\ \ time$$

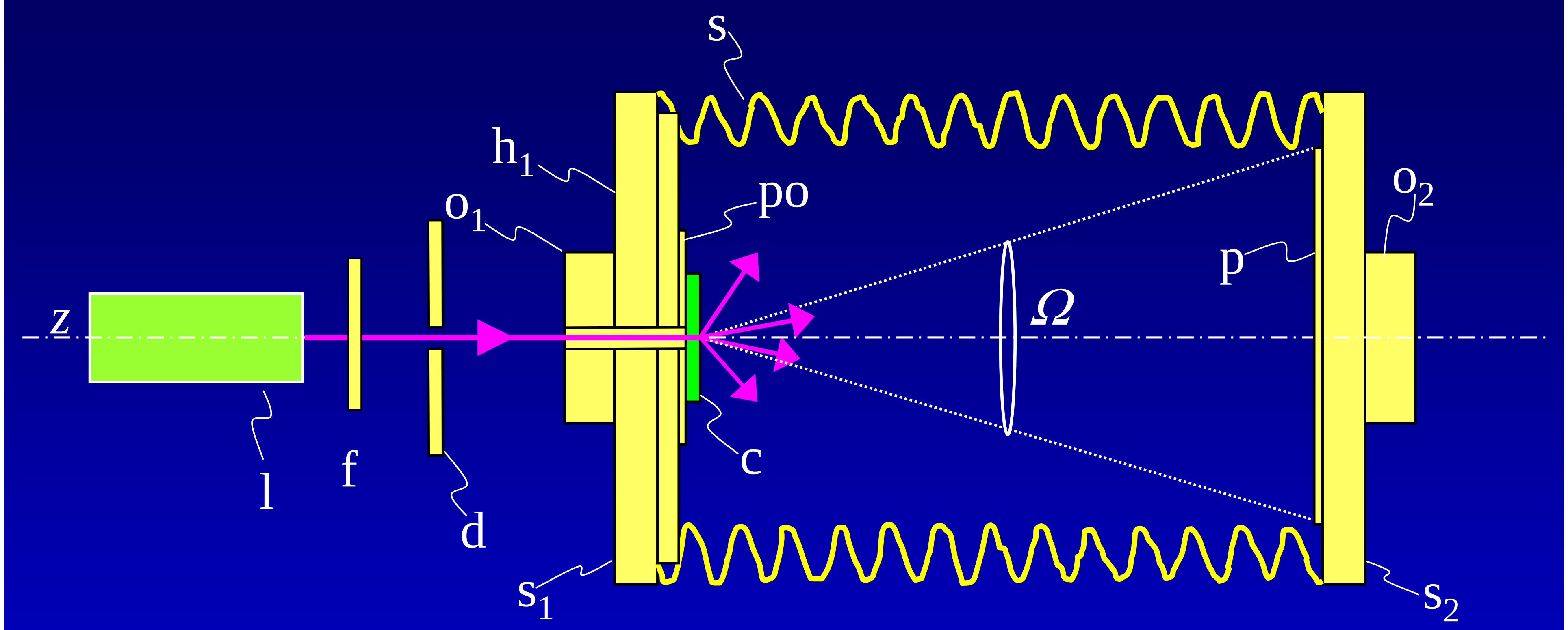
$$\overline{G}_{abs}(d,\lambda,t_0) \propto G_{scat}^{\perp} \cdot \frac{1}{R^2} \cdot \left[1 - \overline{R}(90°,\lambda,t_0)\right]$$

REFLECTION FROM LARGE SAMPLES



For the characterization of large samples (PV modules) a supplementary bellow is inserted on the back of the photocamera.

TRANSMISSION THROUGH SMALL SAMPLES



By reversing the position of the light source and by inserting a new shutter on the back side, it is possible to record the scattered light transmitted by semitransparent samples.

Examples: textured TCO/glass samples, used as front windows in PV devices.

CONCLUSIONS

☻ A camera, CARDIFF, for recording the light scattered from textured PV samples has been presented.

☻ CARDIFF can work in reflection, in transmission, on small and large samples.

☻ CARDIFF can be designed in order to collect light on a plane or cylindrically shaped photographic plate.

☻ CARDIFF produces a negative film which can be scanned and transferred to a computer for analysis of the scattered image.

Thanks a lot

for your attention