How colorPol® polarizers work

Polarization – A fascinating property of light

Polarization explained

Light can be depicted as a transverse electromagnetic wave (figure 1). Deduced from Maxwell's equations the magnetic field vector is perpendicular to the magnetic field and the propagation direction. Thus, typically the propagation direction and the electrical field vector will be named only, the magnetic field vector can be derived.

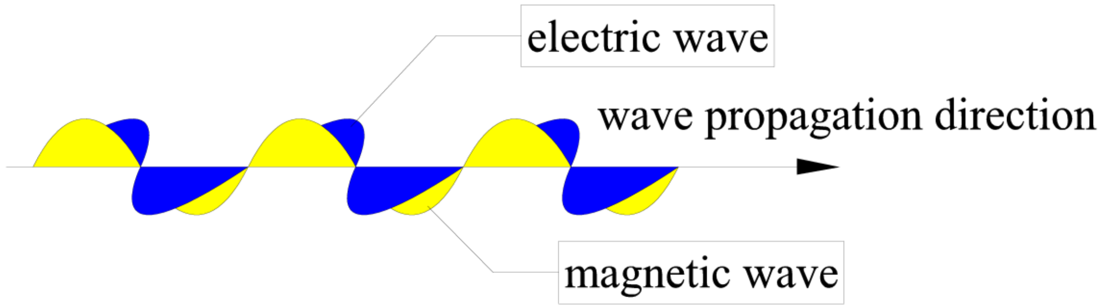


Figure 1 Electromagnetic wave

The electrical field vector can be free in space but perpendicular to propagation direction. Applying a 3-dimensional, orthogonal coordinate system with y-axis common to propagation direction, the normalized electrical field vector can have any direction in the x-z-plane. The angle of the electrical field vector in polar coordinates of the x-z-plane is called polarization direction of the wave (figure 2).

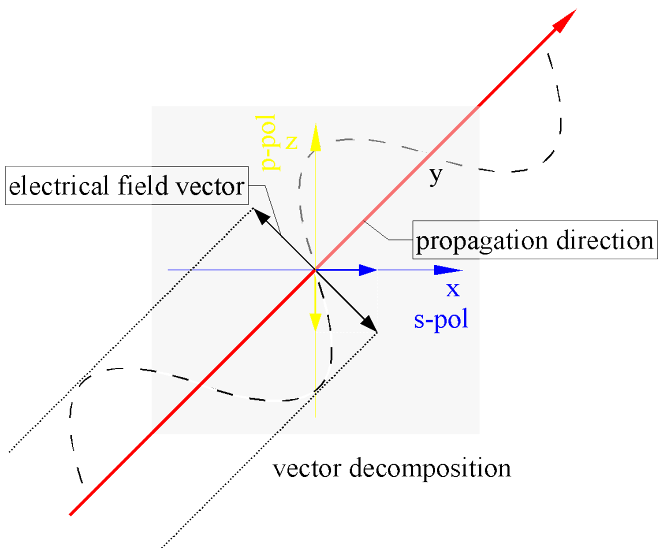


Figure 2 Wave train with its components

Light is a collection of many wave trains. Every electromagnetic wave (corresponding to a photon) is fully characterized by

- wavelength
- propagation direction
- electrical field vector
- phase shift to another wave train

By this, light is classified as follows:

- Monochromatic light: all wave trains have the same wavelength
- Polarized light: all wave trains have the same electrical field vector
- Coherent light: monochromatic light with same phase (no phase shift)

Steinfeldstr. 3, 39179 Barleben, Germany · +49 39203 9630 · colorPol@codixx.de · www.codixx.de

Design of colorPol® polarizers

The colorPol® polarizer is a thin soda lime glass plate with silver nano particles embedded near both surfaces (figure 3). The base glass is about 250 µm thick. The thickness of the silver particle containing region depends on the colorPol® type and ranges from 1 µm to 10 µm. The refractive index is 1,52 and largely same over the whole component regardless the nano particles.

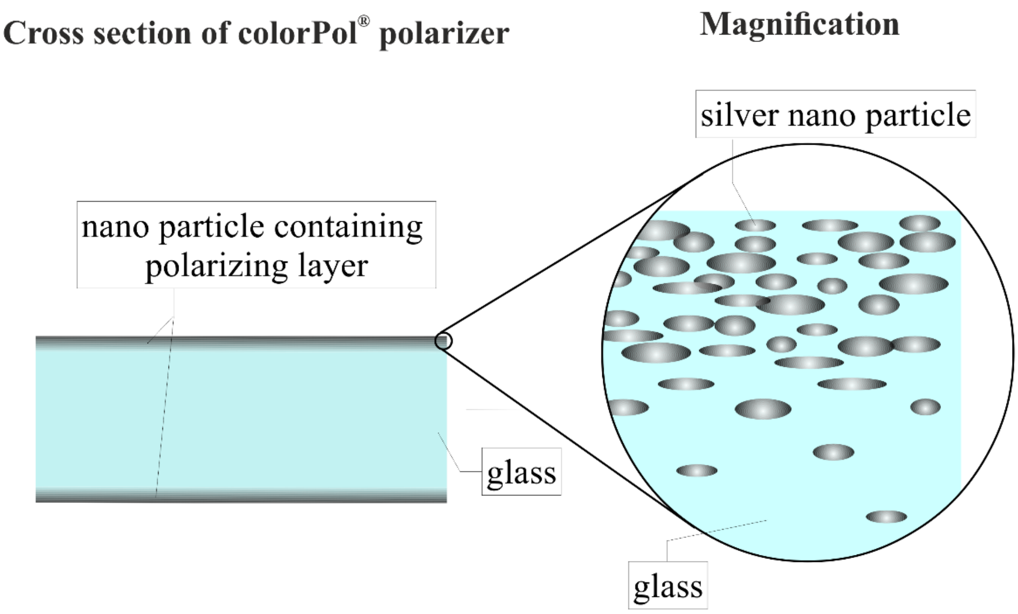


Figure 3 Design of colorPol® polarizers

The silver nano particles are prolate ellipsoids with their long axes aligned exactly parallel to each other. This is fundamental for the excellent polarization properties. Due to the fact that the colorPol® filter has no layers of different materials but is made from the same base glass, there are no barriers for the light. The refractive index of 1,52 is same for the complete filter. The glass of the colorPol® filter is transparent from ca. 320 nm until about 3 µm. Only the prolate silver nano particles can cause polarization dependent absorption and reflection in the range of 340 nm 420 nm and 450 nm 3 µm.

The silver nano particles containing region can be removed by glass etching technologies. Thus, single sided polarizers with better transmittance but less contrast are possible as well as patterned polarizers using lithography.

Principle of function

Each nano particle acts as a polarization dependent and wavelength selective absorber - like a dipol antenna. When an electromagnetic wave hits the particle, its free electrons are excited. It has been well known for many years and called Mie plasmon (Gustav Mie, 1869-1957) or surface plasmon.

Depending on the direction of the oscillating electrical field relative to the particle's axes, higher or lower frequencies are in resonance (figure 4). In respect to light it means, only long wave light polarized parallel to the particle's long axis will be absorbed while long wave light of perpendicular polarization will be transmitted. This can be used to polarize long wave light

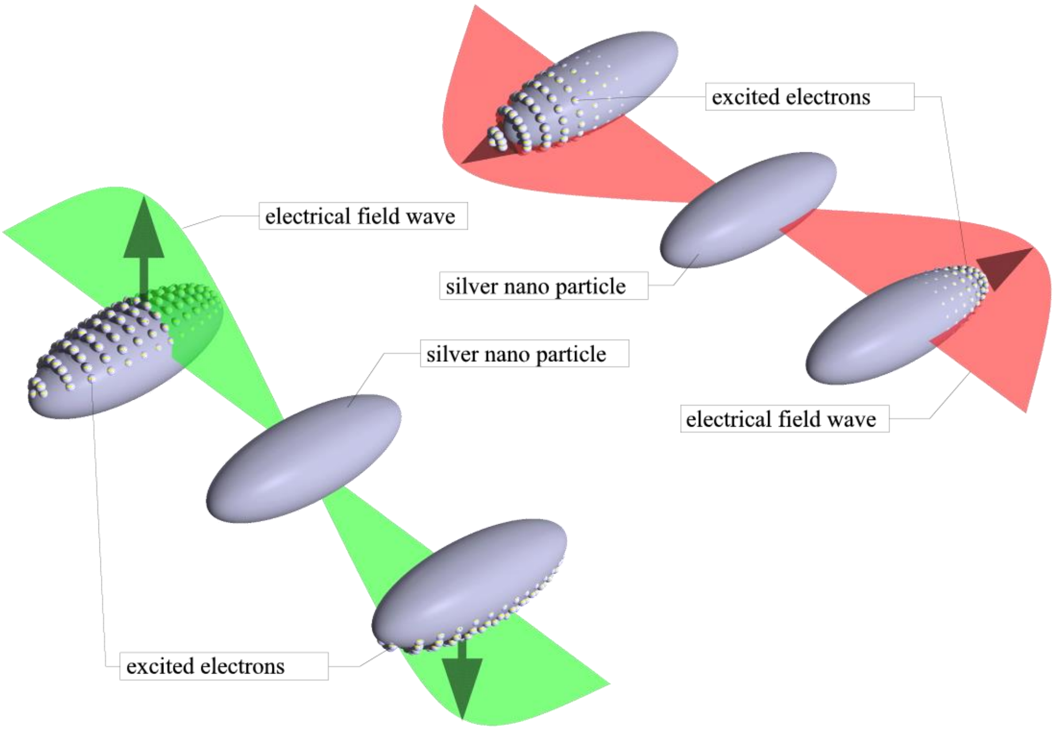


Figure 4 Plasmon - by electromagnetic wave excited electrons

The same is true for short wave light, but axes interchanged. For the special combination of glass with silver nano particles the resonance frequencies are about 365 nm - 405 nm for the particle's short axis and about 420 nm - 5 µm for the particle's long axis (figure 5). These resonance frequencies strongly depend on particle's size and axis ratio. The larger the axis ratio the remote the polarization dependent resonance frequencies.

Making a polarizer using this excellent physical principle means to embed a huge number of particles in glass with their axes aligned precisely parallel. To cover a wide wavelength range, particles different in size and axis ratio are necessary.

Steinfeldstr. 3, 39179 Barleben, Germany · +49 39203 9630 · colorPol@codixx.de · www.codixx.de

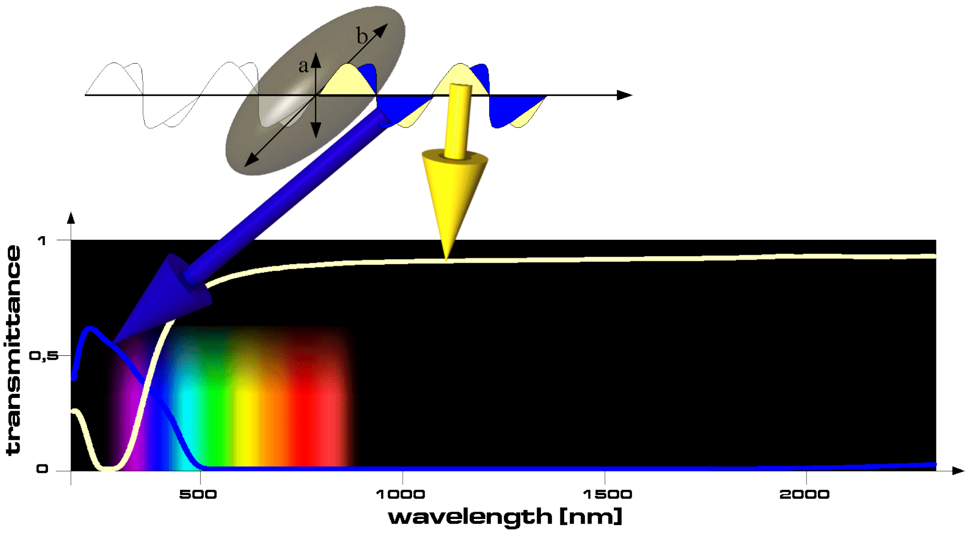


Figure 5 Transmittance curve after passing aligned elangated silver nano particles

Properties of colorPol® polarizers

The colorPol® filters show no birefringence. The light passing the filter becomes polarized. That means, one polarization direction will be blocked, the perpendicular direction will be transmitted. The acceptance angle is very large without minimizing the polarization effect.
Some types of filters reflect the blocked light; thus, the reflected light is also polarized but with a poor degree of polarization. The reflection behavior for transmitted light is regular and same as for transparent glass.

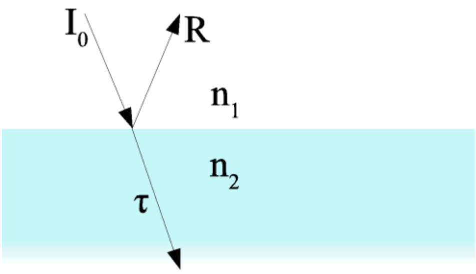


Figure 6 Reflection at boundary layers

The reflection R on a boundary layer (figure 6) is given by $R = \frac{(n_2-n_1)^2+(\kappa_2-\kappa_1)^2}{(n_2+n_1)^2+(\kappa_2+\kappa_1)^2}$, whereas n_x are the real parts of the complex refractive indices and κ is the extinction coefficient or the imaginary part of the entered medium respectively. κ is determined by the absorption index α: $\kappa = \frac{\lambda \cdot \alpha}{4 \cdot \pi}$.
The absorption index α is defined by the absorption of light in a nontransparent medium $\alpha = -\frac{\ln(\frac{I}{I_0})}{l}$, where l is the path length and $\frac{I}{I_0}$is the transmittance.
For transparent materials the imaginary part is near zero, hence the formula can be simplified to $R = \frac{(n_2-n_1)^2}{(n_2+n_1)^2}$. This is valid for the transmitted light with colorPol® polarizers. For the blocked polarization κ is not zero and must be considered. The reflection is directed and caused by the high absorption index of the thin, polarization dependent, particle containing domain.

The surface of colorPol® polarizers is common soda lime glass and can be coated with usual materials to minimize reflections caused by the differing real parts of the refractive indices. The reflection caused by absorption remains unaffected. The polarizer can be tilted to dispel the reflection.

Since the raw colorPol® filters are very thin, there is nearly no dispersion. For instance, this is very important for a Femto-Second Laser with its wide spectrum.

The thin polarizers have a good surface and only few wavefront distortions which can be improved by lamination between two sheets of glass. After grinding and polishing the wavefront distortion is lower than $\lambda/4$.

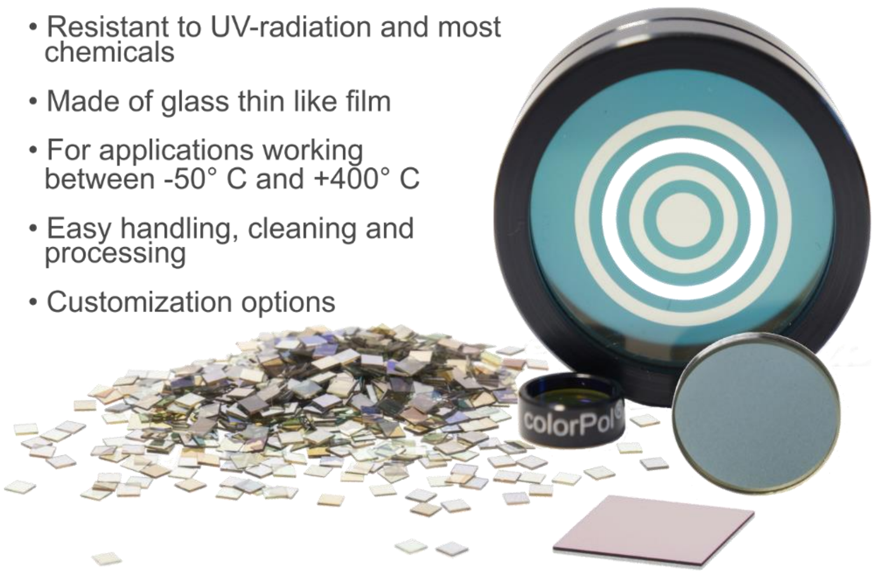
Due to the absence of any halides or organic material, colorPol® filters are very resistant against low or high temperatures and long-term stable under UV exposing. As the material is glass, it withstands most acids and solvents.

colorPol® polarizers

Quality made in Germany

for UV, VIS, NIR & MIR

- Excellent transmission up to >96 %
- High contrast ratio >10^5:1 (50 db)
- Resistant to UV-radiation and most chemicals
- Made of glass thin like film
- For applications working between -50° C and +400° C
- Easy handling, cleaning and processing
- Customization options



Steinfeldstr. 3, 39179 Barleben, Germany · +49 39203 9630 · colorPol@codixx.de · www.codixx.de