

## Second Harmonic Generation

**Second Harmonic Generation [SHG]** is a non-linear light scattering effect that is restricted to high light intensities and very specific specimen – like cell membranes, microtubules or collagen fibers. In opposite to classical stray light that has exactly the same wavelength like the light source SHG light has exactly half the wavelength.

As SHG is based on light scattering and not on fluorescence, photo bleaching and –toxicity are significantly reduced.

### Physics behind SHG

Light scattering and so SHG are based on the polarization of organic or inorganic matter by electromagnetic radiation (light). For low intensities the polarization  $P$  of matter is directly proportional to the electric field  $E$  of the electromagnetic radiation.

$$P \approx E$$

If the electrical field  $E$  will be increased to an order similar to the electrical field within atoms or molecules the polarization  $P$  becomes proportional to higher terms of the electrical field.

$$P \approx aE + bE^2 \dots$$

Electromagnetic radiation  $E$  is defined by its wavelength  $\lambda$  and its amplitude  $E_0$  (power).

$$E(\omega t) = E_0 \sin(\omega t); \quad \omega = \frac{2\pi}{\lambda}$$

Therefore the relation between polarization and electromagnetic radiation can be written as:

$$P \approx aE_0 \sin(\omega t) + bE_0 E_0 \sin^2(\omega t)$$

With the mathematical theorem

$$\sin^2(x) = \frac{1}{2}(1 - \cos(2x))$$

the resulting polarization is proportional to

$$P(\omega t) \approx aE_0 \sin(\omega t) - bE_0 E_0 \cos(2\omega t) + c.$$

As the resulting polarization  $P(\omega t)$  is proportional to the doubled frequency  $\cos(2\omega t)$  the polarized matter emits light with exactly half of the wavelength of the original wavelength. The factor  $b$  is called second order susceptibility  $\chi^{(2)}$ , which has to be unequal zero to make SHG effect happen. For complex physical symmetry reasons  $\chi^{(2)}$  will be unequal zero if the molecular structure of the specimen is non centro symmetric. Collagen fibers, microtubules and membranes for example show this behavior.