

Vakuum Maxwell Gleichungen

$$\operatorname{div} \vec{E} = \hat{\rho} / \varepsilon_0$$

$$\operatorname{div} \vec{B} = 0$$

$$\operatorname{rot} \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\operatorname{rot} \vec{B} = \mu_0 \hat{J} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t} \vec{E}$$

μ_0, ε_0 sind Vakuum Konstanten

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Materie

$$\operatorname{div} \vec{D} = \rho$$

$$\operatorname{div} \vec{B} = 0$$

$$\operatorname{rot} \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\operatorname{rot} \vec{H} = \vec{J} + \frac{\partial}{\partial t} \vec{D}$$

Materialgleichungen

$$\rho = \hat{\rho} + \rho_M(\vec{E}, \vec{B})$$

$$\vec{J} = \hat{J} + \vec{J}_M(\vec{E}, \vec{B})$$

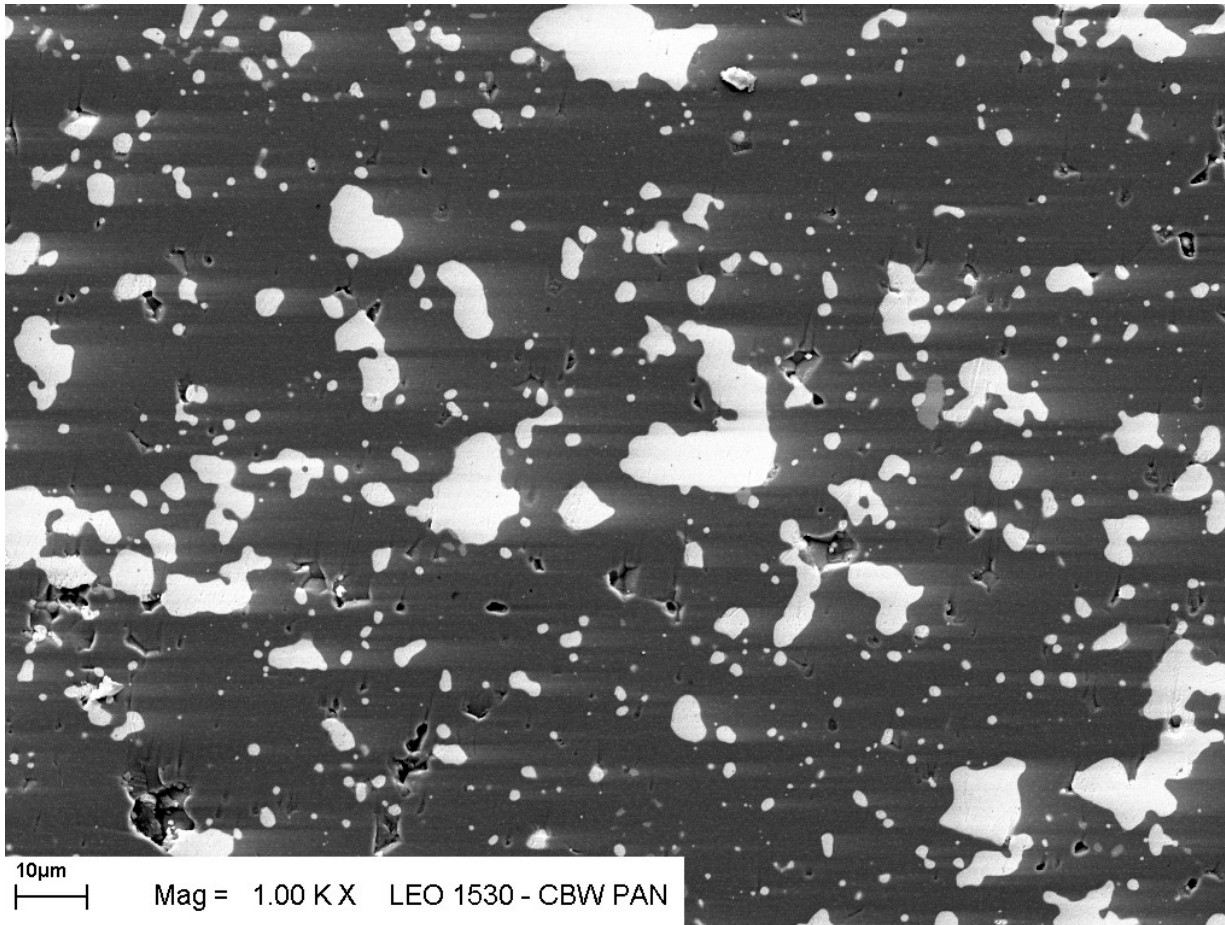
einfacher Sonderfall (linear, isotrop, frequenzunabhängig):

$$\rho_M(\vec{E}, \vec{B}) = (\varepsilon - \varepsilon_0) \operatorname{div} \vec{E} \rightarrow \vec{D} = \varepsilon \vec{E}$$

$$J_M(\vec{E}, \vec{B}) = \dots \rightarrow \vec{B} = \mu \vec{H}$$

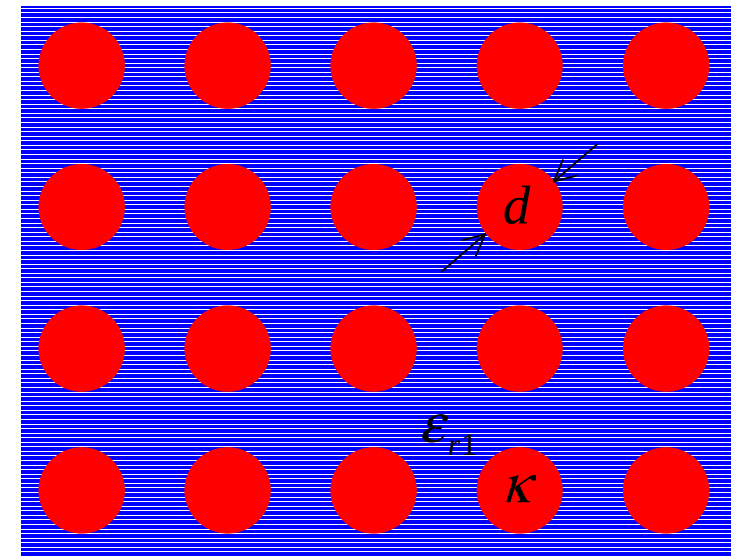
artificial dielectric

matrix material e.g. Al_2O_3 $\epsilon_r \approx 10$
+ metal powder e.g. Mo $\kappa \approx 18 \cdot 10^6 \text{ 1}/\Omega\text{m}$



simple model:

spherical particles in cubic lattice
dielectric matrix ϵ_{r1}
conducting spheres d, κ
volume fill factor v
dipole theory



makroskopische Gleichungen

$$\vec{D} = \epsilon(\omega) \vec{E}$$

$$\vec{B} = \mu(\omega) \vec{H}$$

linear, isotrop, frequenzunabhängig

$$\left. \begin{array}{l} \frac{\partial}{\partial t} \text{rot } \vec{E} = -\frac{\partial^2}{\partial t^2} \vec{B} \\ \text{rot} \left(\frac{1}{\varepsilon} \frac{\partial}{\partial t} \vec{D} \right) \\ \text{rot } \vec{H} - \vec{J} \end{array} \right\} \quad \text{rot} \left(\frac{1}{\varepsilon} \text{rot } \vec{H} \right) - \text{rot} \left(\frac{1}{\varepsilon} \vec{J} \right) = -\mu \frac{\partial^2}{\partial t^2} \vec{H}$$

$$\left. \begin{array}{l} \frac{\partial}{\partial t} \text{rot } \vec{H} = \frac{\partial}{\partial t} \vec{J} + \frac{\partial^2}{\partial t^2} \vec{D} \\ \dots \end{array} \right\} \quad -\text{rot} \left(\frac{1}{\mu} \text{rot } \vec{E} \right) = \frac{\partial}{\partial t} \vec{J} + \varepsilon \frac{\partial^2}{\partial t^2} \vec{E}$$

homogen $\varepsilon(\vec{r}) = \text{const}$, $\mu(\vec{r}) = \text{const}$

$$-\text{rot}(\text{rot } \vec{H}) - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{H} = -\text{rot } \vec{J}$$

$$-\text{rot}(\text{rot } \vec{E}) - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{E} = \mu \frac{\partial}{\partial t} \vec{J}$$

linear, isotrop, frequenzunabhängig, homogen

$$\begin{aligned} -\operatorname{rot}(\operatorname{rot} \vec{H}) &= \nabla^2 \vec{H} - \operatorname{grad}(\operatorname{div} \vec{H}) \\ \operatorname{div} \vec{H} &= \frac{1}{\mu} \operatorname{div} \vec{B} = 0 \end{aligned}$$

$$\begin{aligned} -\operatorname{rot}(\operatorname{rot} \vec{E}) &= \nabla^2 \vec{E} - \operatorname{grad}(\operatorname{div} \vec{E}) \\ \operatorname{div} \vec{E} &= \frac{1}{\varepsilon} \operatorname{div} \vec{D} = \frac{\rho}{\varepsilon} \end{aligned}$$

inhomogene Wellengleichung

$$\begin{aligned} \nabla^2 \vec{H} - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{H} &= -\operatorname{rot} \vec{J} \\ \nabla^2 \vec{E} - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{E} &= \mu \frac{\partial}{\partial t} \vec{J} + \frac{1}{\varepsilon} \operatorname{grad} \rho \end{aligned}$$

mit Leitfähigkeit $\vec{J} = \kappa \vec{E} + \vec{J}_e$

$$\begin{aligned} \nabla^2 \vec{E} - \mu \kappa \frac{\partial}{\partial t} \vec{E} - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{E} &= \mu \frac{\partial}{\partial t} \vec{J}_e + \frac{1}{\varepsilon} \operatorname{grad} \rho \\ \nabla^2 \vec{H} - \mu \kappa \frac{\partial}{\partial t} \vec{H} - \mu \varepsilon \frac{\partial^2}{\partial t^2} \vec{H} &= -\operatorname{rot} \vec{J}_e \end{aligned}$$

