Friedrich-Schiller-Universität Jena

Carrier density noise in ET

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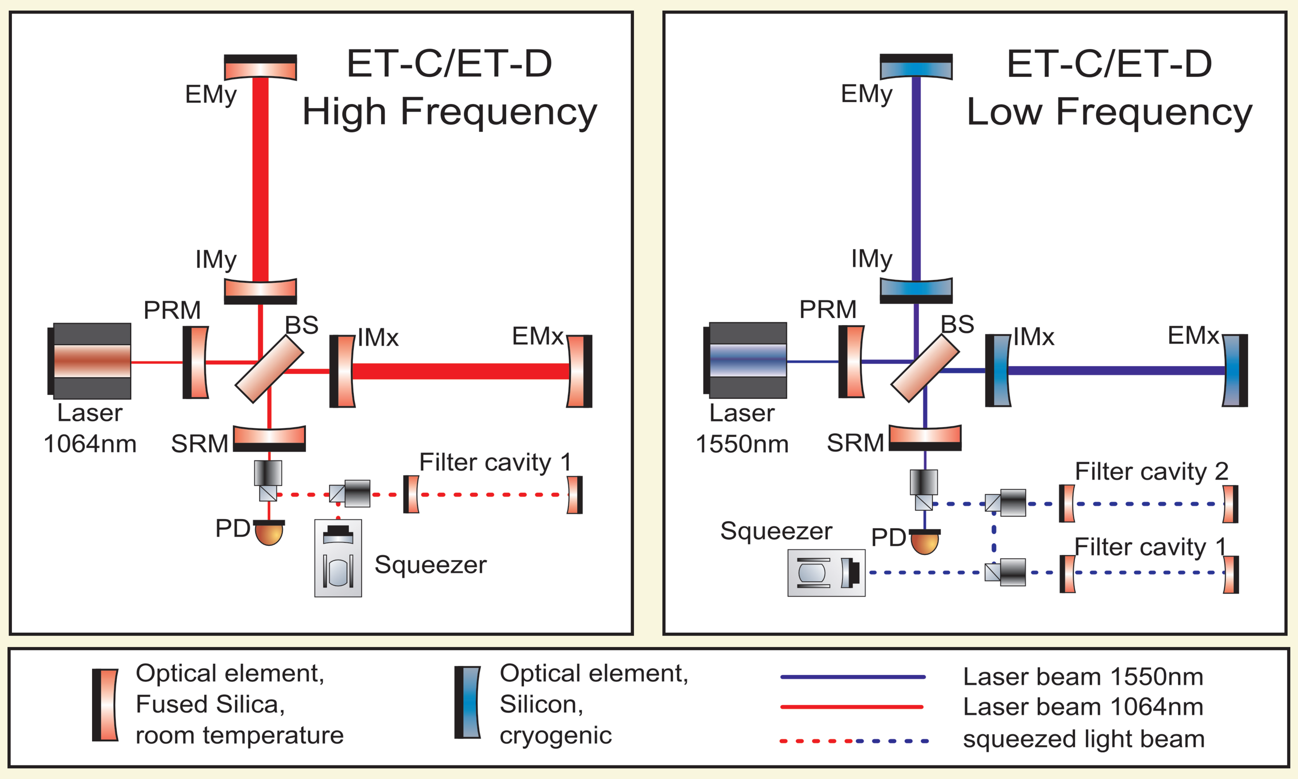
Abstract

In contrast to fused silica as test mass material in current gravitational wave detectors, silicon represents a semiconductor. Thus, driven by thermal energy free electrons and holes are diffusing through the crystal. Via the effect of free carrier dispersion in silicon, i.e. the dependence of the refractive index on the free carrier density, such a diffusion introduces a noise process into transmissive optical components of the detector.

In this poster we present a theoretical analysis of carrier density noise and apply it to the proposed ET-LF design. Further, we evaluate its impact on the ET design goal and discuss possibilities to mitigate the effect of carrier density noise.

Einstein Telescope

· Xylophone principle: ET-LF with cryogenic mirrors and moderate optical power
ET-HF at room temperature and high optical power



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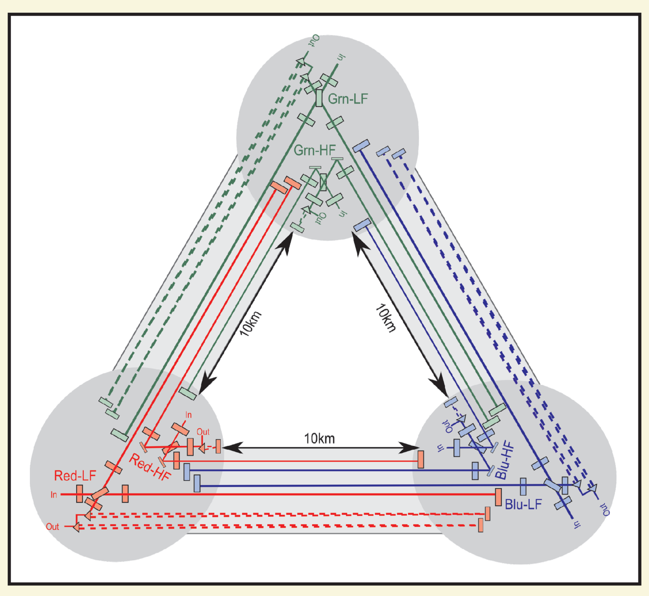
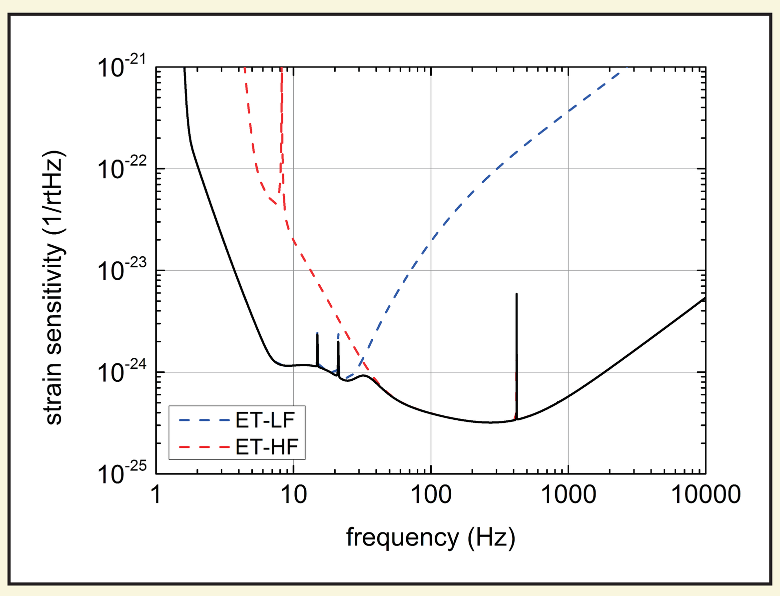
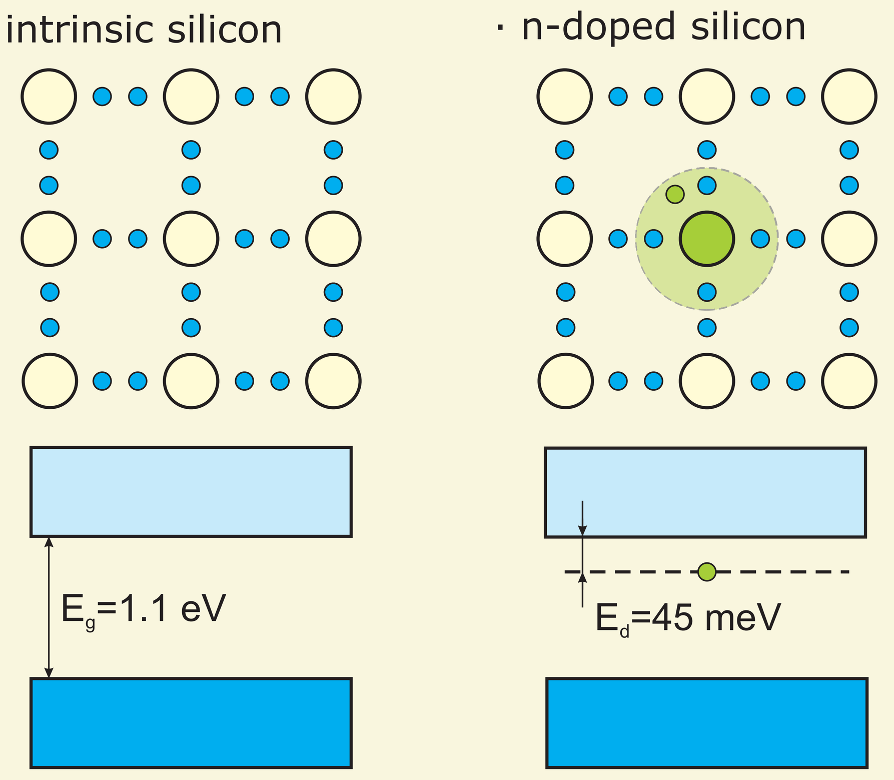


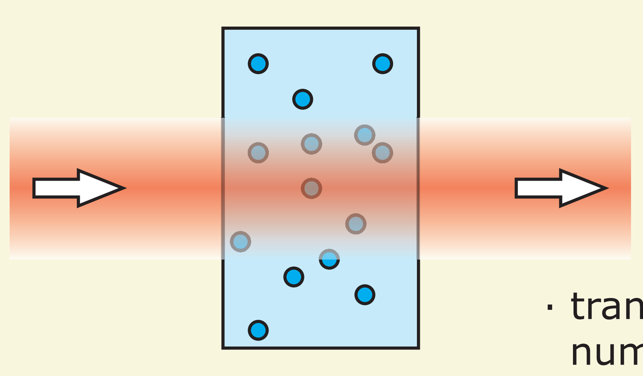


Silicon as ET-LF substrate material

· intrinsic silicon · n-doped silicon



· free carriers moving through the crystal



· transmitted light senses different number of free carriers

Free Carrier Dispersion

· refractive index n is affected by the concentration of free holes n_h and electrons n_e

$$n = -8.8\times10^{-22}\left(\frac{n_e}{\mathrm{cm}^{-3}}\right) - 8.5\times10^{-18}\left(\frac{n_h}{\mathrm{cm}^{-3}}\right)^{0.8}$$ [2]

Diffusional CD noise

· Langevin approach for carrier concentration driven by random force F(r,t)

$$\frac{\partial n}{\partial t}(r,t) - D\Delta n(r,t) = F(r,t)$$

· correlator of fluctuating forces

$$\langle F(\boldsymbol{k},\omega)F^*(\boldsymbol{k}',\omega')\rangle = (2\pi)^4\,F_0^2 k^2\delta(\boldsymbol{k}-\boldsymbol{k}')\delta(\omega-\omega')$$

· normalization of F_0 by thermodynamic equation

$$\langle\Delta N^2\rangle_V = k_B T\left(\frac{\partial n}{\partial\mu}\right)V$$ [3]

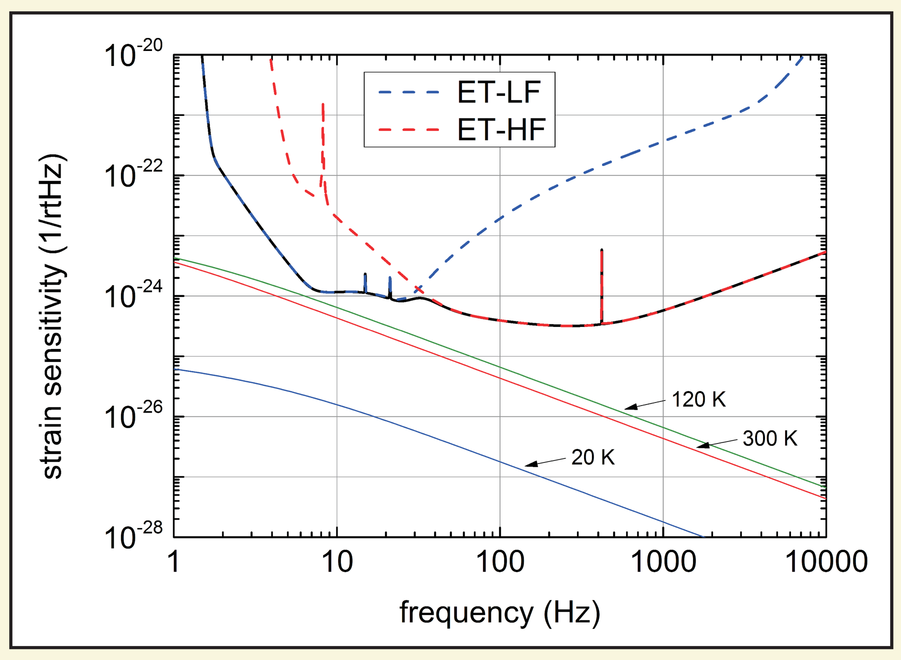
· displacement noise

$$S_z(\omega) = \frac{2}{\pi}k_B T\frac{\partial n}{\partial\mu}\gamma^2 H\int_0^\infty dk\,\frac{Dk^3 e^{-k^2 r_0^2/2}}{\omega^2 + D^2k^4}$$

· strain noise

$$S_h(\omega) \simeq \frac{2S_z(\omega)}{L^2\left(\frac{2F}{\pi}\right)^2}$$

· H=46 cm
· w_0=9 cm
· L=10 km
· F=880
· $n_{dop}=10^{14}$ cm^{-3}
· $\gamma_e=-8.8\times10^{-22}$ cm^{-3}



Recombination CD noise

· even without diffusion (D=0) excitation/recombination of free carriers induces CD noise

· Langevin approach using deviation from mean carrier density η

$$\frac{\partial\eta}{\partial t}(r,t) + \frac{\eta(r,t)}{\tau_0} = F(r,t)$$ with correlator $$\langle F(\boldsymbol{r},t)F^*(\boldsymbol{r}',t')\rangle = F_0\delta(\boldsymbol{r}-\boldsymbol{r}')\delta(t-t')$$

· normalization of F_0 by

$$\langle\Delta N^2\rangle_V = k_B T\left(\frac{\partial n}{\partial\mu}\right)V \approx nV$$

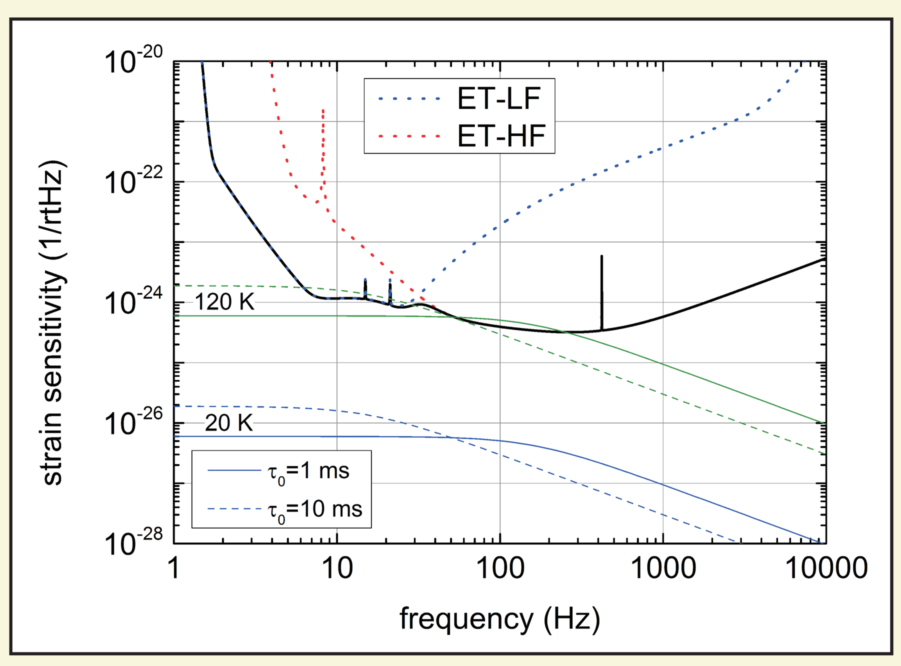
· displacement noise

$$S_z(\omega) = \frac{2}{\pi}\frac{H}{r_0^2}\frac{\gamma^2 n\,\tau_0}{1+\omega^2\tau_0^2}$$

· recombination time τ_0

τ_0~10 ms for FZ Si
τ_0~0.5 ms for CZ Si

[4]



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