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Stress-Optical Coefficients of 157 nm Materials

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Stress-Optical Coefficients at 157 nm

- Need to determine effect of grown-in stress on optical properties
- Need to calculate the effect of external stress
- Unknown for CaF_2, BaF_2, and any other material in the VUV

Effect of stress σ_{ij} on optical properties given by:

$$\Delta(K^{-1})_{ij} = q_{ijkl}\sigma_{kl} \quad \Leftrightarrow \quad (\Delta(K^{-1})_i = q_{ij}\sigma_j \text{ abbreviated notation})$$

$q_{ijkl} \equiv$ piezo-optic tenser (4$^{\text{th}}$ rank)

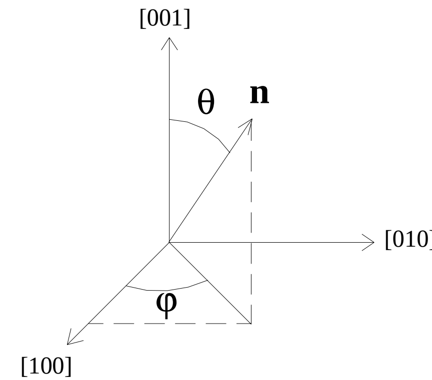
For cubic crystals with fluorite structure Fm3m (classes –43m,432,m3m)

Crystal symmetry $\Rightarrow$ 36 components $\rightarrow$ 3 independent components: q_{11}, q_{12}, q_{44}

$$q_{ij} = \begin{pmatrix} q_{11} & q_{12} & q_{12} & 0 & 0 & 0 \\ q_{12} & q_{11} & q_{12} & 0 & 0 & 0 \\ q_{12} & q_{12} & q_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & q_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & q_{44} \end{pmatrix}$$

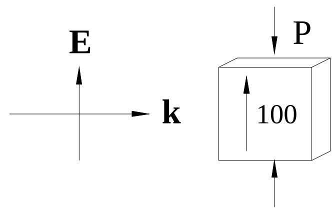
For uniaxial stress σ in direction $\hat{n} = \hat{x}_1 \sin\theta\cos\varphi + \hat{x}_2 \sin\theta\sin\varphi + \hat{x}_3 \cos\theta$

$$\begin{pmatrix} \Delta(K^{-1})_1 \\ \Delta(K^{-1})_2 \\ \Delta(K^{-1})_3 \\ \Delta(K^{-1})_4 \\ \Delta(K^{-1})_5 \\ \Delta(K^{-1})_6 \end{pmatrix} = \sigma \begin{pmatrix} q_{11}\sin^2\theta\cos^2\varphi + q_{12}(\sin^2\theta\sin^2\varphi + \cos^2\theta) \\ q_{11}\sin^2\theta\sin^2\varphi + q_{12}(\sin^2\theta\cos^2\varphi + \cos^2\theta) \\ q_{11}\cos^2\theta + q_{12}\sin^2\theta \\ q_{44}\sin\theta\cos\theta\sin\varphi \\ q_{44}\sin\theta\cos\theta\cos\varphi \\ q_{44}\sin^2\theta\sin\varphi\cos\varphi \end{pmatrix}$$



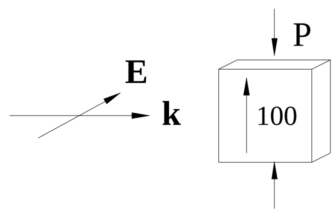
But for stress along cube axes and cube diagonals, index uncouples coefficients:

q_{11}



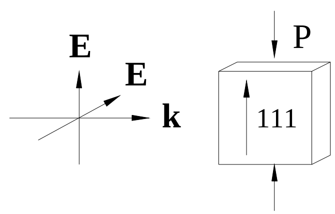
$\Delta n_{\parallel} = (n^3/2)\, q_{11}\, P$ [100]

q_{12}



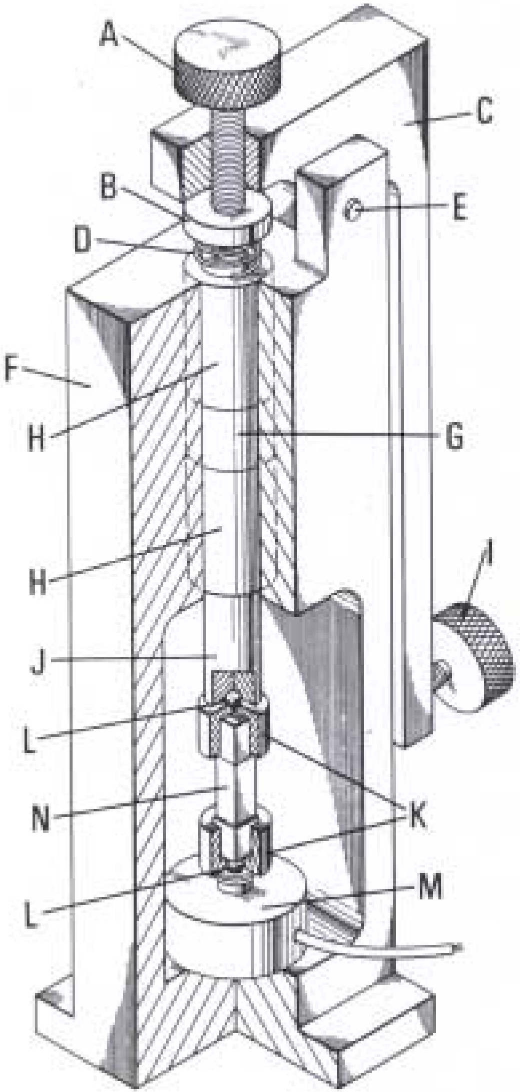
$\Delta n_{\perp} = (n^3/2)\, q_{12}\, P$ [100]

q_{44}



$\Delta n_{\parallel} - \Delta n_{\perp} = (n^3/2)\, q_{44}\, P$ [111]

Uniaxial Stress Apparatus



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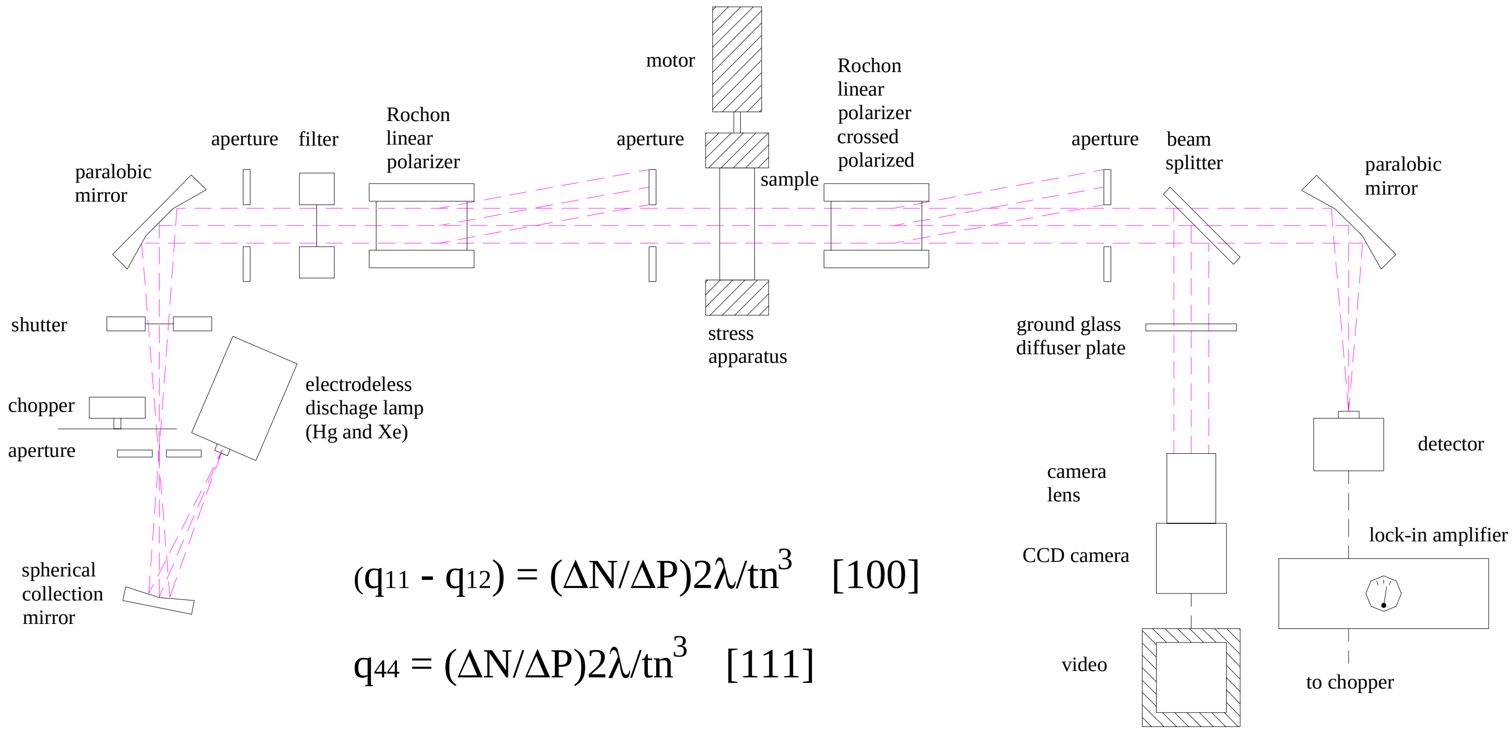
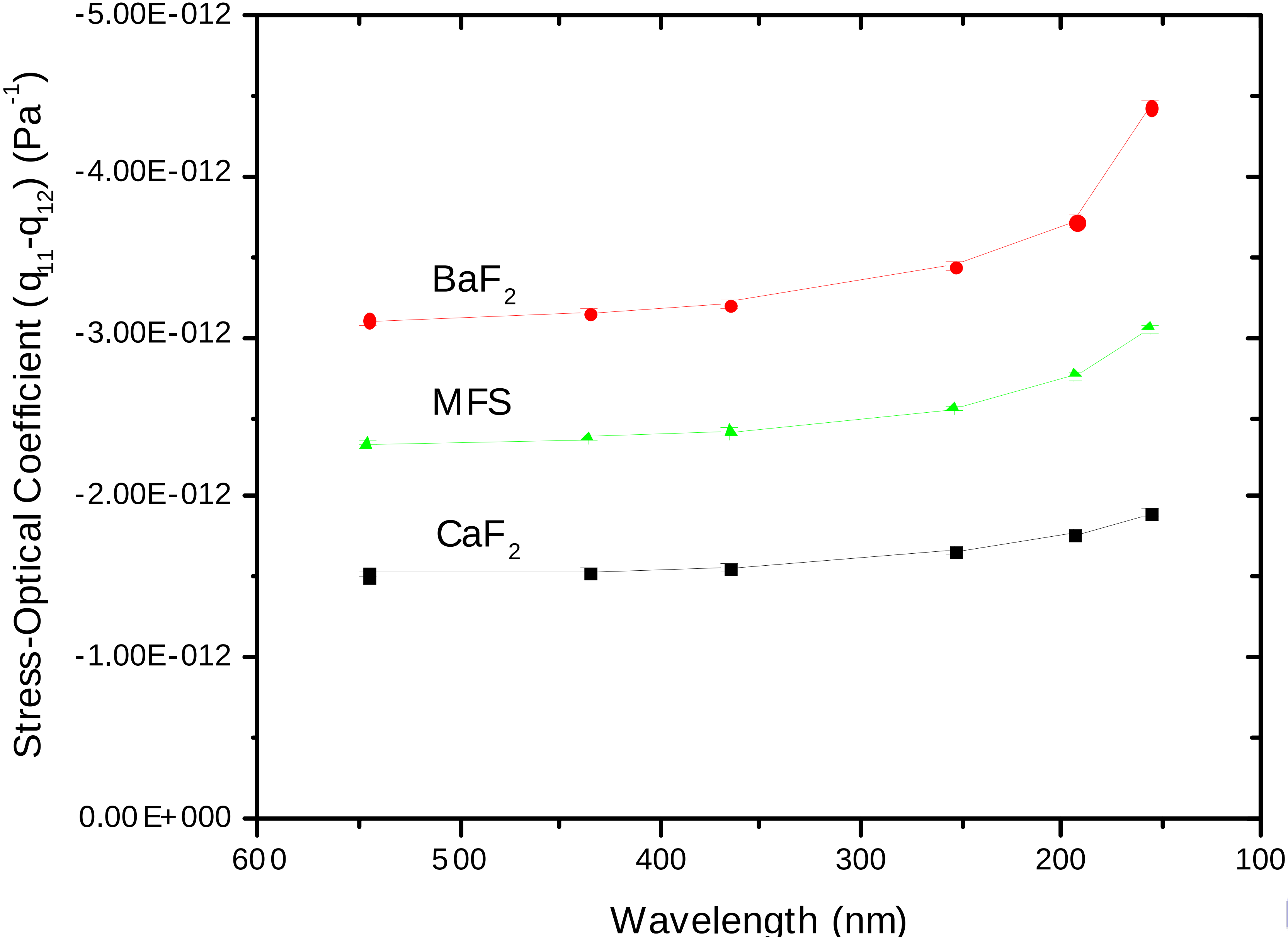
Stress-Induced Birefringence



$$(q_{11} - q_{12}) = (\Delta N/\Delta P)2\lambda/tn^3 \quad [100]$$

$$q_{44} = (\Delta N/\Delta P)2\lambda/tn^3 \quad [111]$$

Stress Birefringence Constant q_{11}-q_{12}



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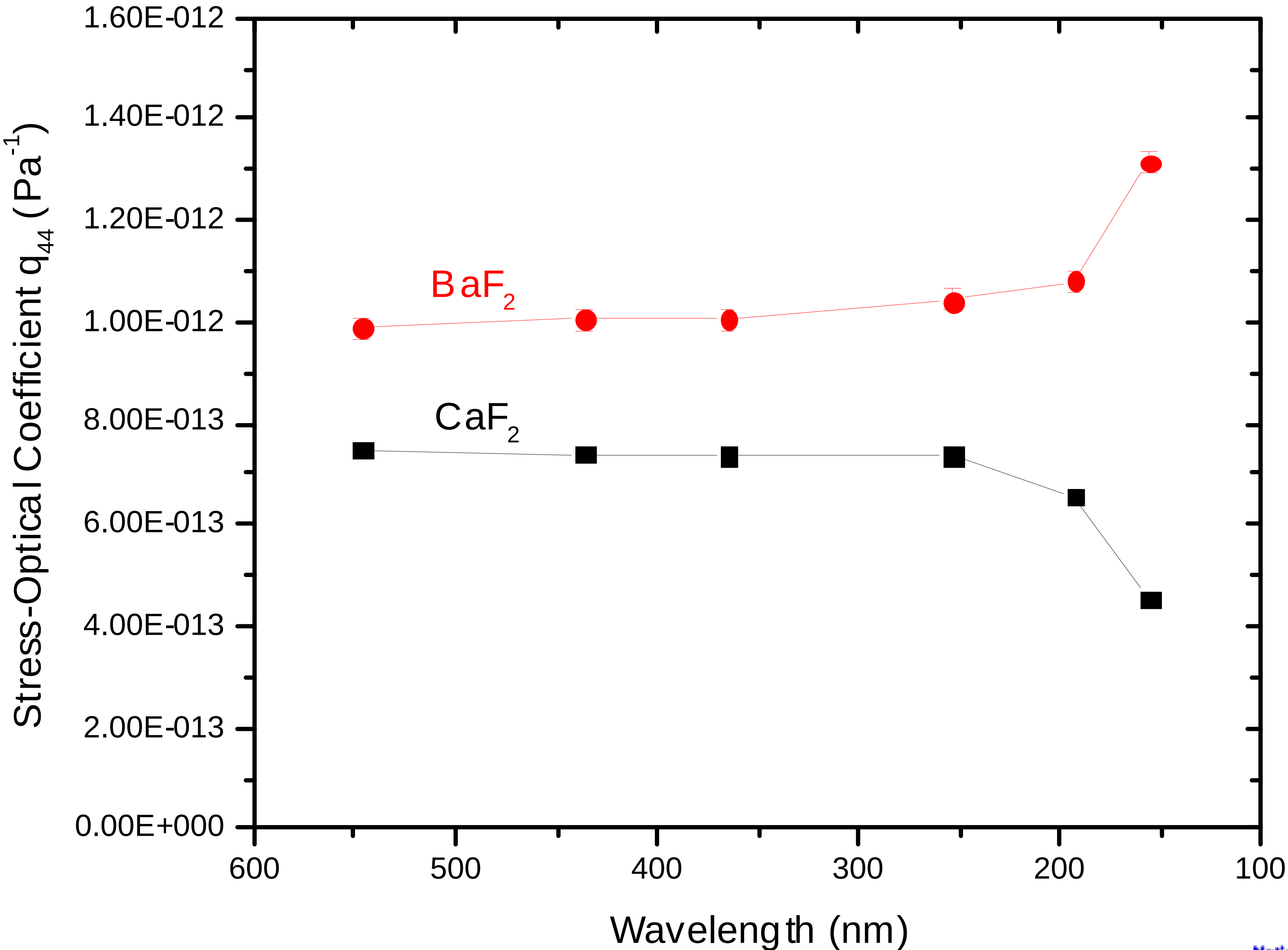
Absolute Stress-Optical Coefficient q_{44}



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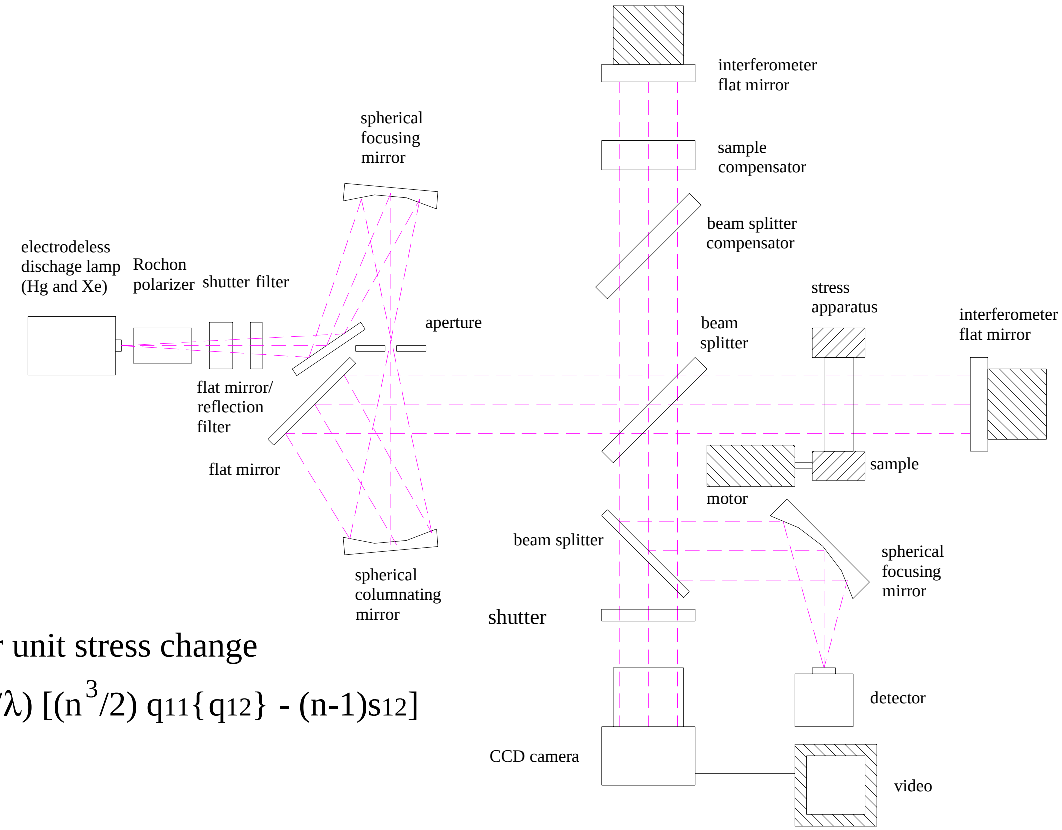
Absolute Stress-Optical Coefficients

Twyman-Green Interferometer



fringe shift per unit stress change

$(\Delta N/\Delta P) = (2t/\lambda)\ [(n^3/2)\ q_{11}\{q_{12}\}\ -\ (n-1)s_{12}]$

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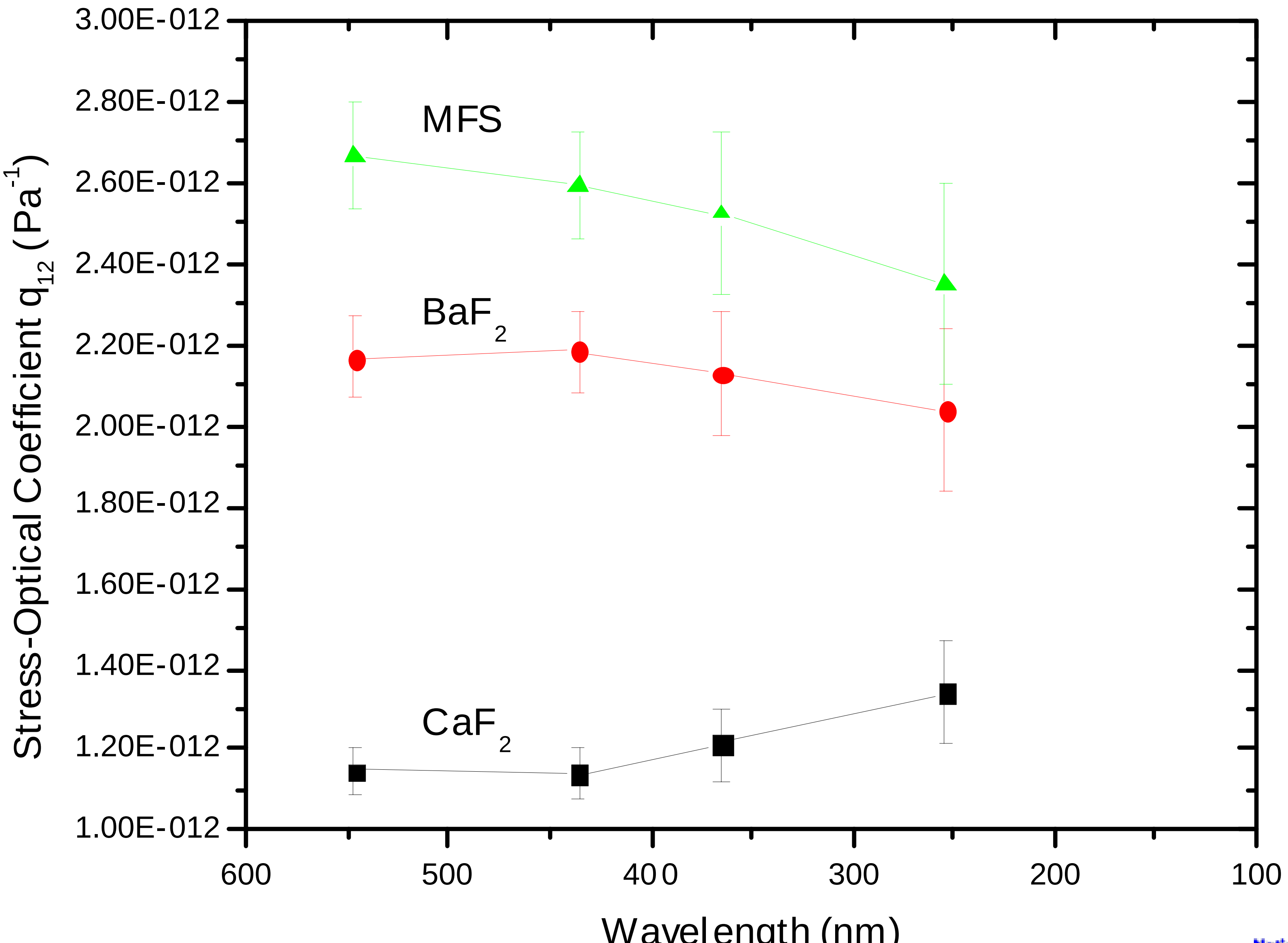
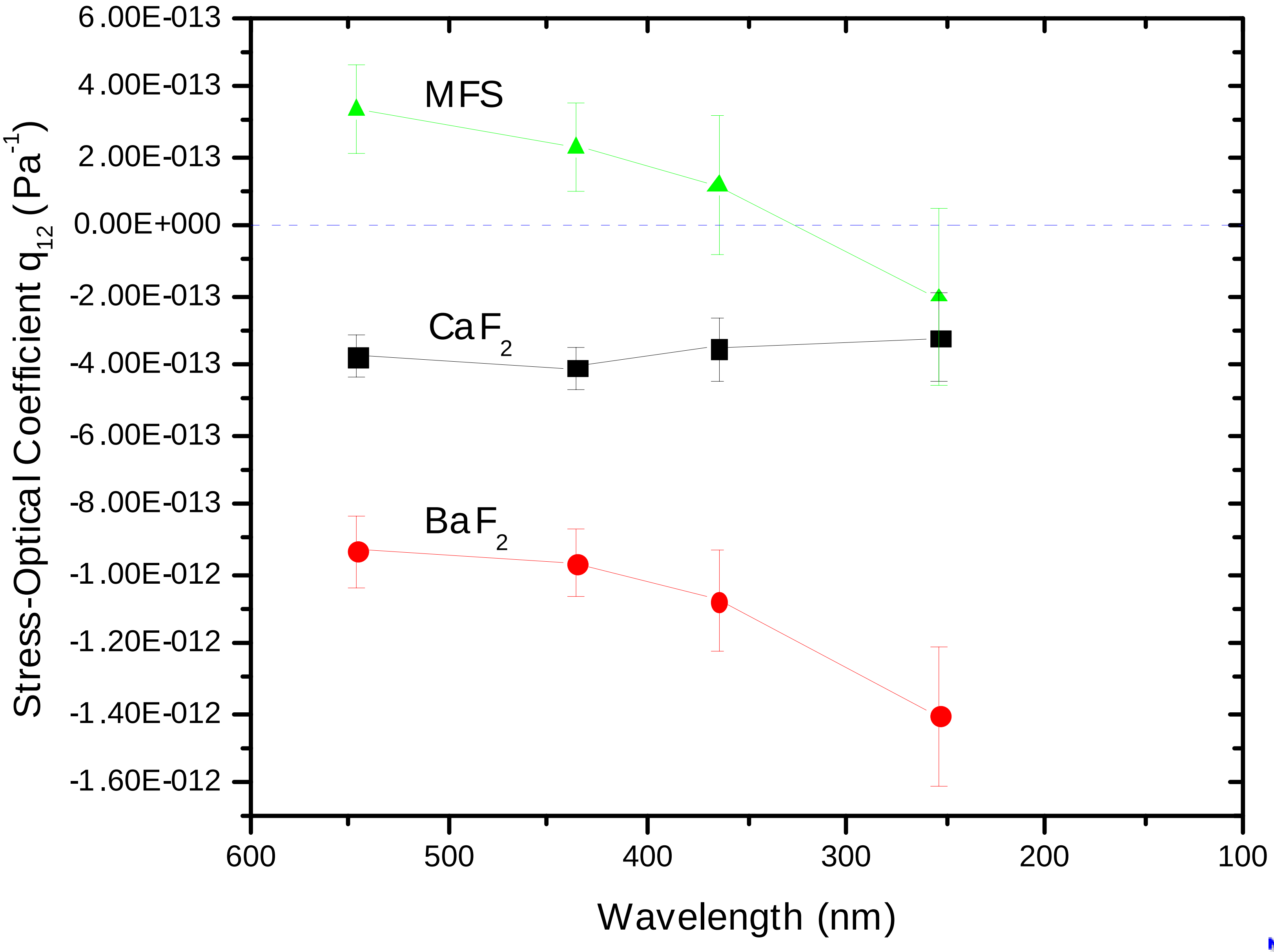
Absolute Stress-Optical Coefficient q_{12}



Absolute Stress-Optical Coefficient q_{11}



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Stress-Birefringence Results

Coefficients (10^{-12} Pa^{-1})	546.38 nm	435.96 nm	365.12 nm	253.73 nm	193.09 nm	156.10 nm	157.63 nm (linear int.)
CaF_2							
q_{11}-q_{12}	−1.53±0.02	−1.55±0.02	−1.57±0.02	−1.66±0.02	−1.77±0.02	−1.91±0.05	−1.90
q_{11}	−0.38±0.06	−0.40±0.06	−0.35±0.05	−0.32±0.05	extrap. −0.3	extrap. −0.3	extrap. −0.3
q_{12}	1.15±0.06	1.15±0.06	1.22±0.09	1.34±0.13	extrap. 1.5	extrap. 1.6	extrap. 1.6
q_{44}	0.75±0.010	0.74±0.01	0.74±0.01	0.73±0.01	0.66±0.01	0.45±0.01	0.46
BaF_2							
q_{11}-q_{12}	−3.10±0.03	−3.15±0.03	−3.21±0.03	−3.44±0.03	−3.71±0.04	−4.42±0.04	−4.39
q_{11}	−0.93±0.10	−0.97±0.10	−1.08±0.15	−1.41±0.20	extrap. −1.7	extrap. −2.4	extrap. −2.4
q_{12}	2.17±0.10	2.18±0.10	2.13±0.15	2.03±0.20	extrap. 2.0	extrap. 2.0	extrap. 2.0
q_{44}	0.99±0.02	1.01±0.02	1.01±0.02	1.04±0.02	1.08±0.02	1.31±0.02	1.30
$mSiO_2$							
q_{11}-q_{12}	−2.34±0.022	−2.37±0.02	−2.41±0.02	−2.55±0.02	−2.76±0.03	−3.04±0.03	−3.03
q_{11}	0.33±0.10	0.22±0.10	0.11±0.15	−0.20±0.15	extrap. −0.4	extrap. −0.8	extrap. −0.8
q_{12}	2.67±0.1.0	2.59±0.10	2.52±0.15	2.35±0.20	extrap. 2.3	extrap. 2.2	extrap. 2.2

Summary

- We have determined the complete set of stress-optical coefficients needed to determine the effect of stress on the index of CaF_2, BaF_2, and a form of VUV fused silica:
  - $(q_{11}-q_{12})$ and q_{44} from the visible through 156 nm
  - q_{11} and q_{12} from the visible through 254 nm
- To obtain these we built a Twyman-Green interferometer that operates on atomic spectral lines from the visible through the fused silica beam splitter cutoff near 200 nm.
- Using our new CaF_2 beam splitter will allow measurements down to below 157 nm (by Jan. 2002.)

To Do:

- Measure the absolute coefficients q_{11} and q_{12} for CaF_2, BaF_2, and fused silica at 157 nm (Jan. 2002)
- Measure the stress-optical coefficients for other important VUV materials, including SrF_2, LiF, and possibly mixed crystals

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