Magnetically Induced Strain In FePd

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Magnetic Materials 3.45

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Format

- Shape memory effect in FePd
  - Shape memory phenomenon
  - Austenite / martensite phases
  - Twinning
- Energetics
  - Magnetic
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  - Lagrangian multiplier method
- Results
- Conclusion

Shape Memory Effect (SME)

- Parent phase - austenite (FCC)
- Cool to form martensite (FCT)
- Twinned structure is energetically favorable
- Stress/magnetic field moves twin/phase boundaries
- Heat to recover strain

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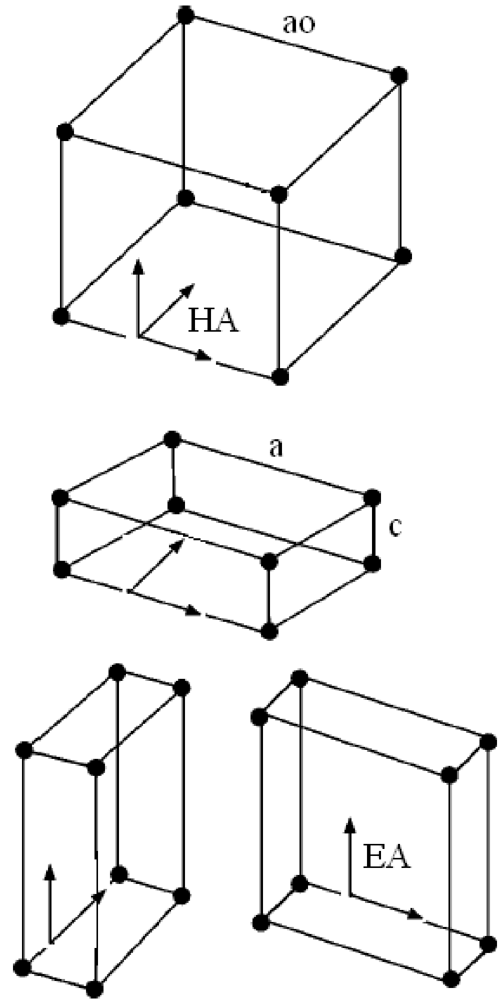
FePd Phases

- Austenite (FCC)
- Martensite (FCT)



Ref. [5]

Twinning

- Minimizing strain energy
  - Slip
    - Breaks more bonds
  - Twinning
    - Breaks less bonds

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Magnetic Field Induced SME

- Magnetic field can move twin and phase boundaries

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Energetics

- Exchange: Neglect
- Magnetic anisotropy:
  - Uniaxial (FCT): $u_a = K_u \, \mathrm{Sin}^2[\theta]$
  - Cubic (FCC): $u_a = K_1 \left(\alpha_1^2 \alpha_2^2 + \alpha_2^2 \alpha_3^2 + \alpha_1^2 \alpha_3^2\right)$
- Magnetoelastic: Insignificant
- Zeeman: $u_z = -M_s . H$
- Elastic strain: $U_e = \frac{1}{2} C_{eff} \, e_{ij}^2$
- Latent Heat: $u_L = 10.79 \left(\frac{\mathrm{erg}}{\mathrm{cm}^3}\right)$

Variants for FePd

- 6 martensitic variants, 3 Austenite

$$\mathbf{E}_1 = \begin{bmatrix} \epsilon_2 & & \\ & \epsilon_1 & \\ & & \epsilon_1 \end{bmatrix}, \quad \mathbf{m}_1^a = m_s(010), \quad \mathbf{m}_1^b = m_s(001),$$

$$\mathbf{E}_2 = \begin{bmatrix} \epsilon_1 & & \\ & \epsilon_2 & \\ & & \epsilon_1 \end{bmatrix}, \quad \mathbf{m}_2^a = m_s(100), \quad \mathbf{m}_2^b = m_s(001),$$

$$\mathbf{E}_3 = \begin{bmatrix} \epsilon_1 & & \\ & \epsilon_1 & \\ & & \epsilon_2 \end{bmatrix}, \quad \mathbf{m}_3^a = m_s(100), \quad \mathbf{m}_3^b = m_s(010).$$

Ref. [4]

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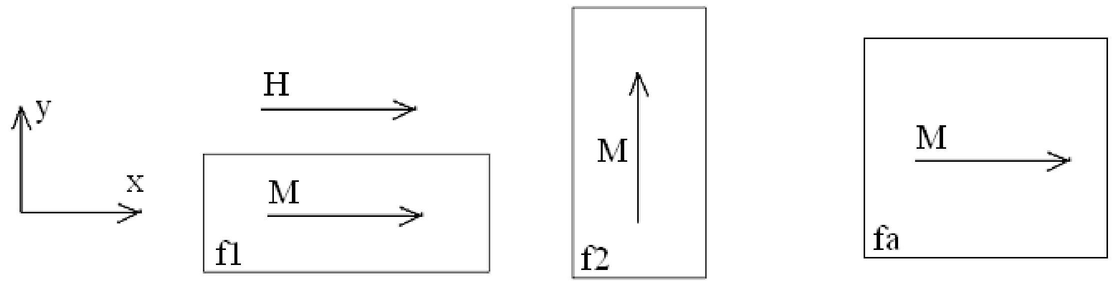
- Quadratic programming problem of 9 variables

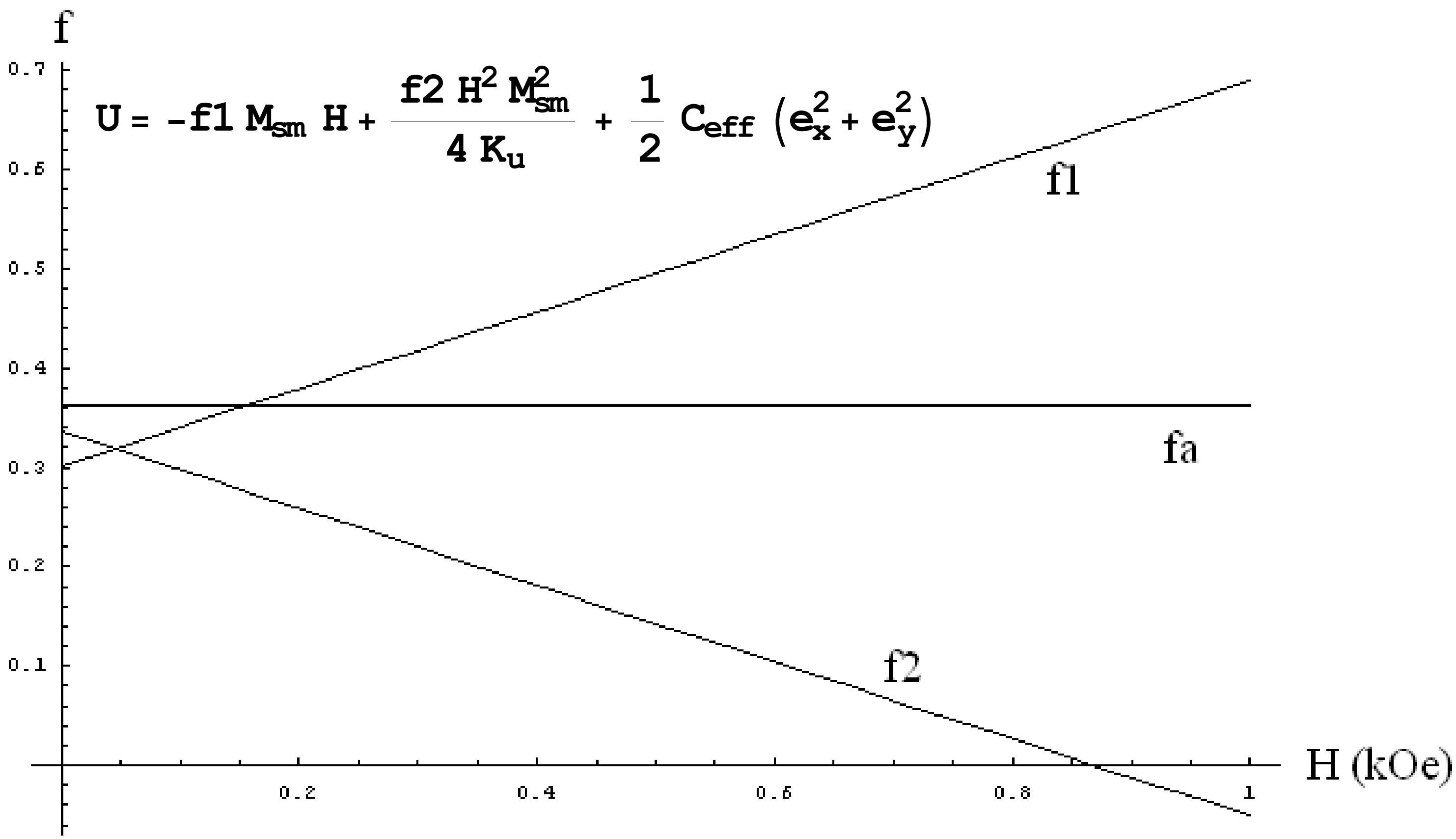
2D Simplification



- Magnetic anisotropy: $U_a = K_u \left(\frac{M_{sm}\ H}{2\ K_u} \right)^2 f2 + K_1 \left(\frac{M_{sa}\ H}{2\ K_1} \right)^2 fa$
- Zeeman: $U_z = -M_{sa}\ H\ fa - M_{sm} . H\ f1$
- Elastic strain: $U_e = \frac{1}{2} C_{eff} \left(e_x^2 + e_y^2 \right)$
- Latent Heat: $U_L = u_L\ (fa - fao)$
- Total: $U = U_a + U_z + U_e + U_L$

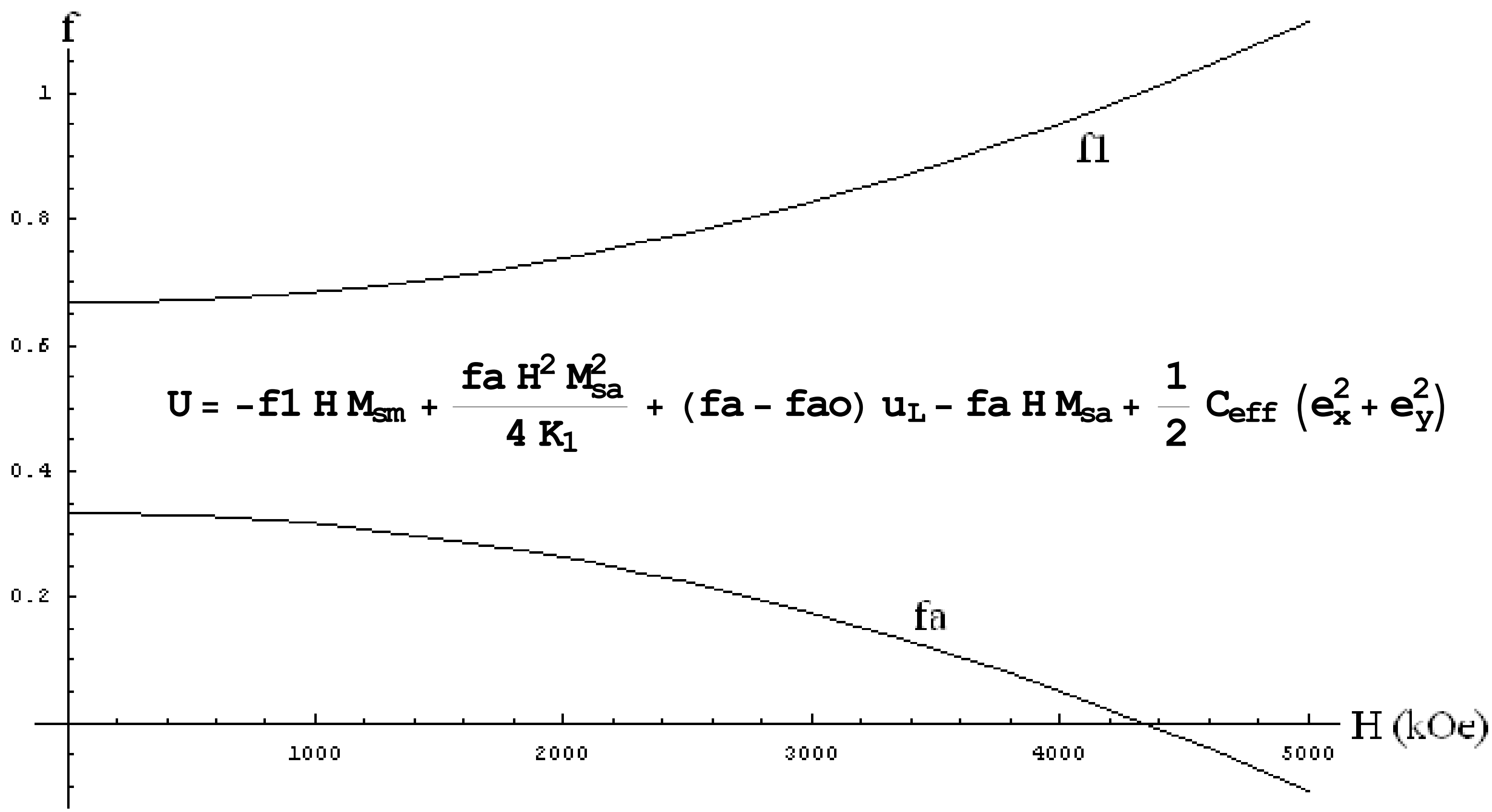
Results

- Volume Fraction vs. Magnetic Field (Low Field)



Results

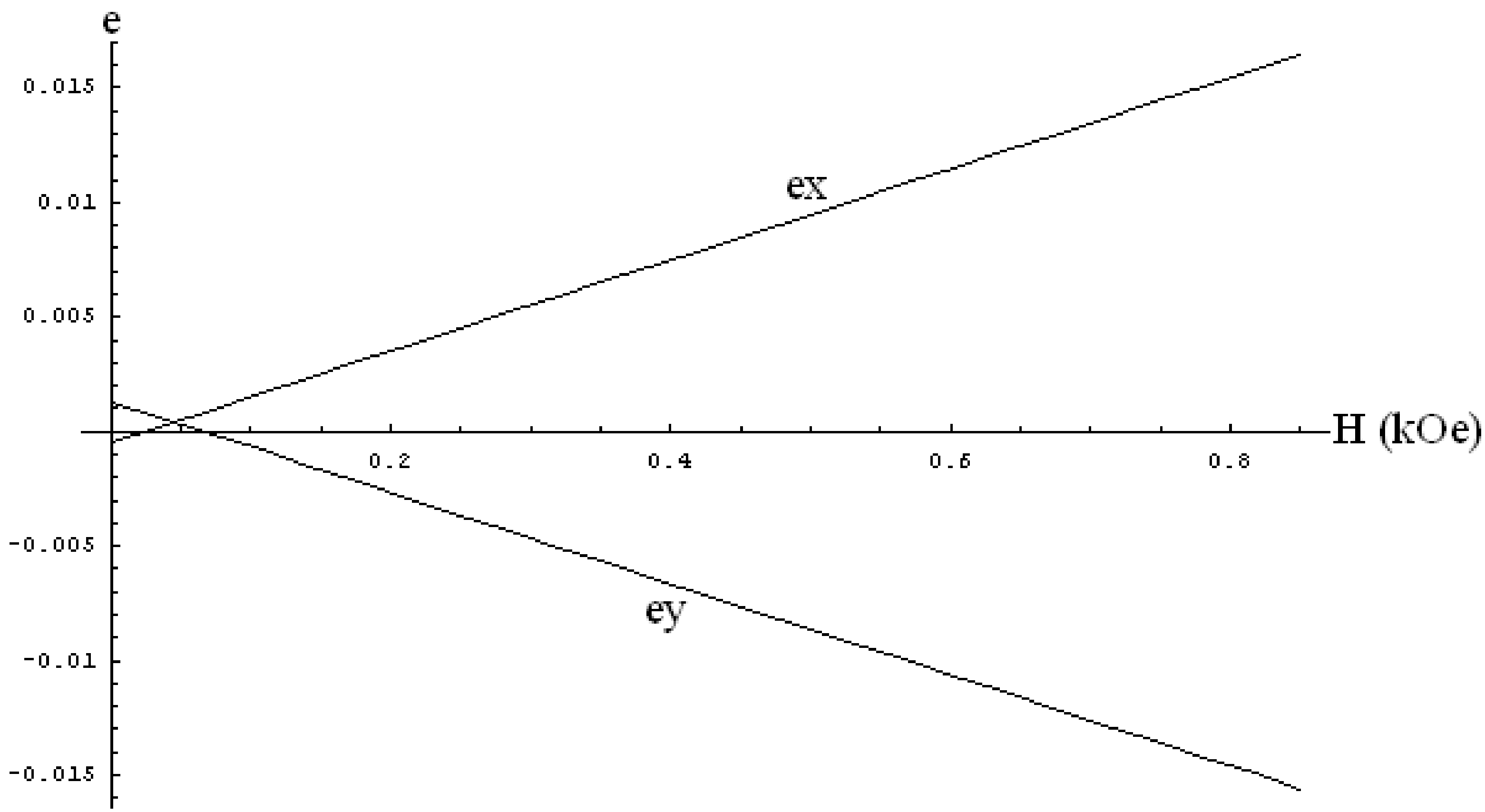
- Volume Fraction vs. Magnetic Field (High Field)



$$U = -f1\,H\,M_{sm} + \frac{fa\,H^2\,M_{sa}^2}{4\,K_1} + (fa - fao)\,u_L - fa\,H\,M_{sa} + \frac{1}{2}\,C_{eff}\left(e_x^2 + e_y^2\right)$$

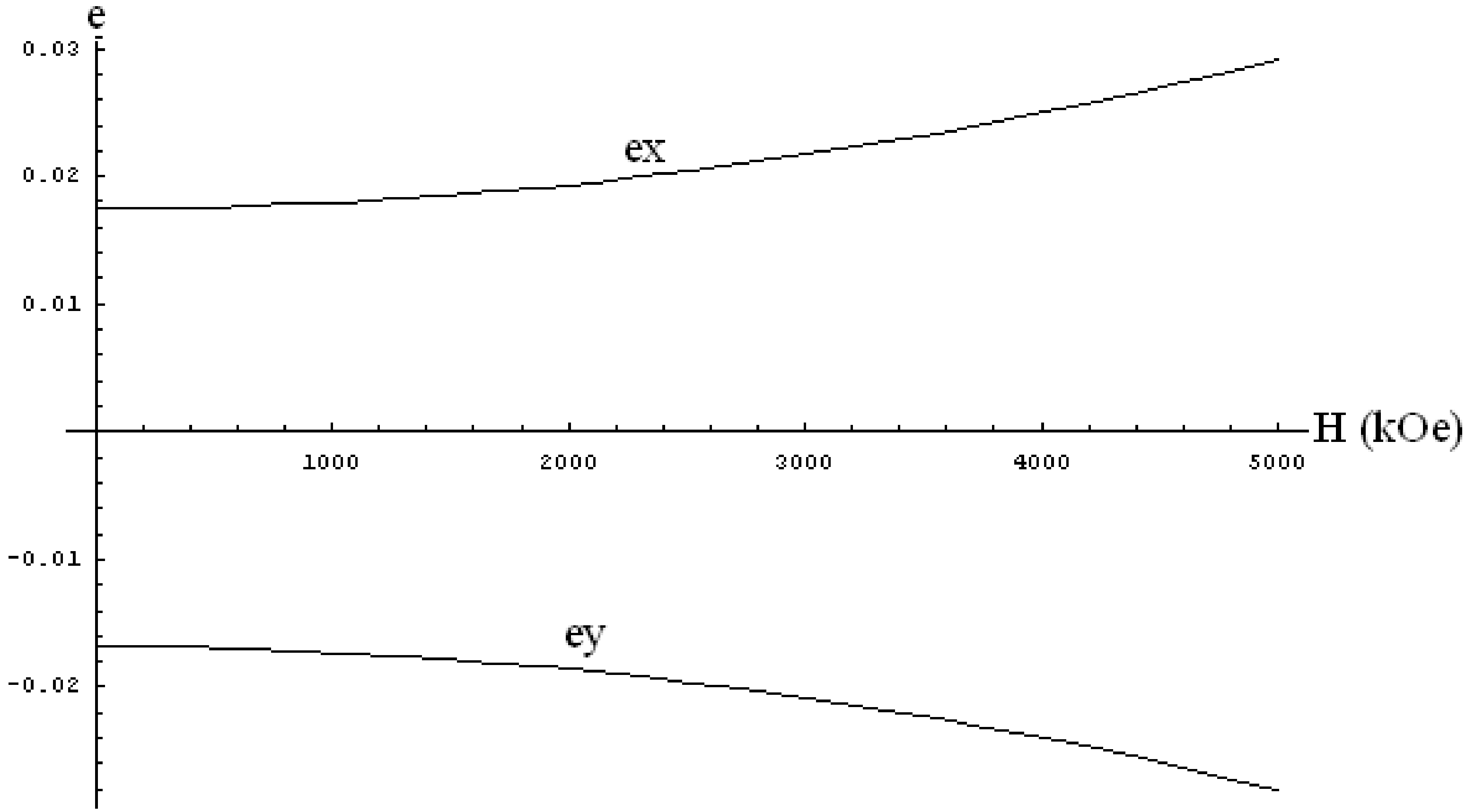
Results

- Strain vs. Magnetic Field (Low Field)



Results

- Strain vs. Magnetic Field (High Field)



Conclusion

- Low field (H ~ 1 kOe)
  - Twin boundary motion
  - Linear strain response (e ~ 1.5%)
  - Negligible phase transformation
- High Field (H ~ 1000 kOe)
  - Phase boundary motion
  - Nonlinear strain response (e ~ 3.0%)
  - Full phase transformation

References

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