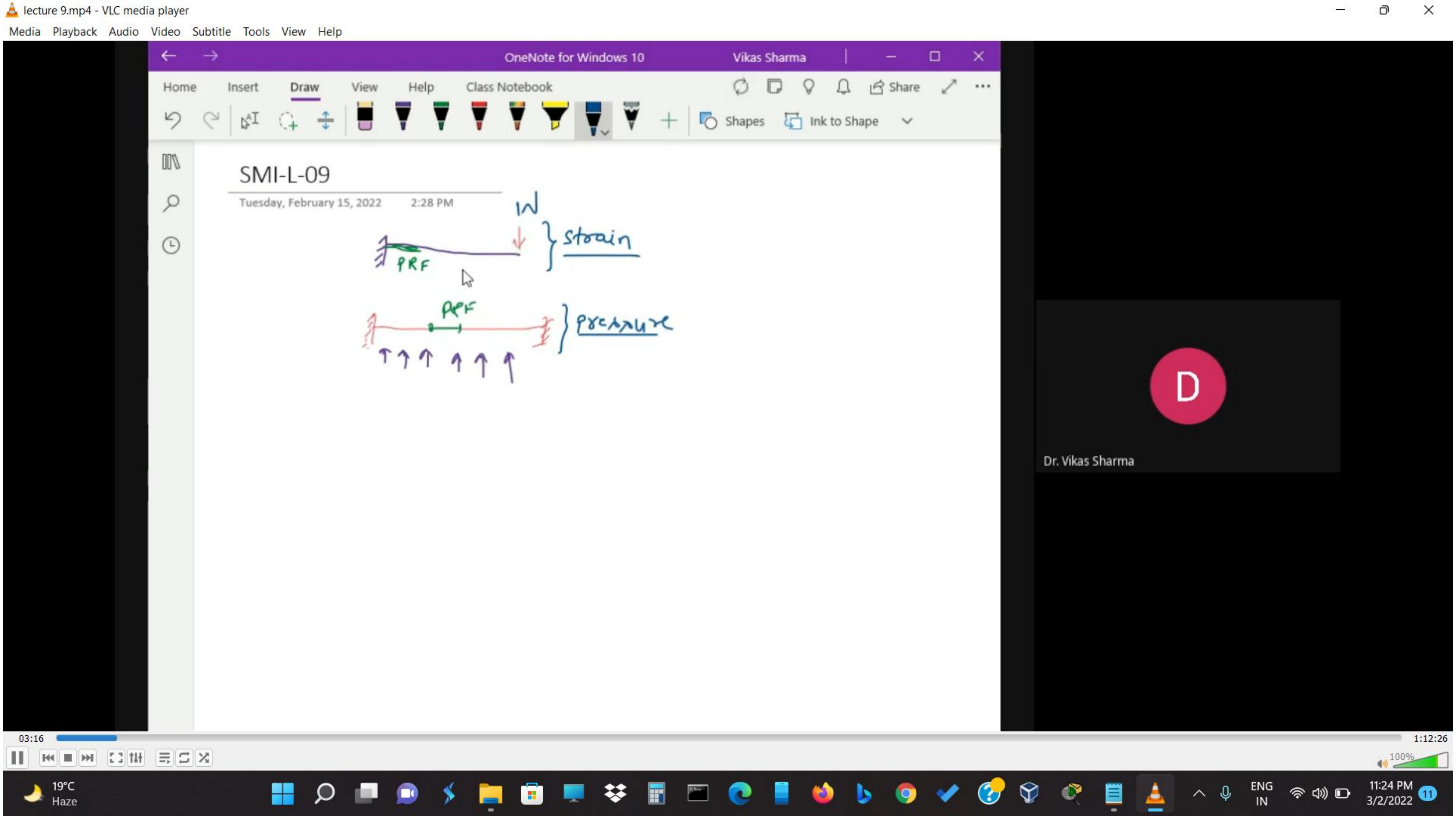
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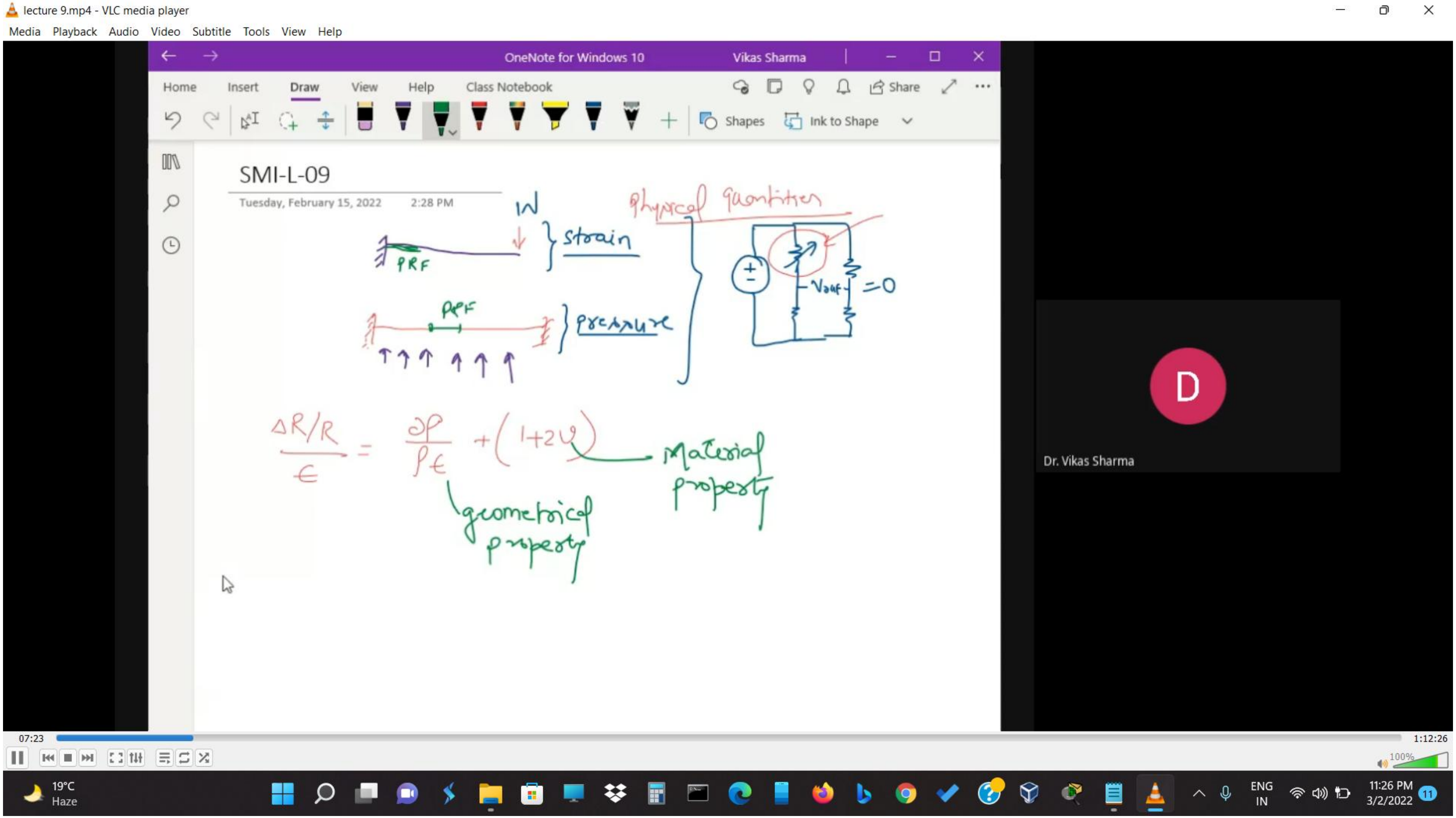
SMI-L-09
Tuesday, February 15, 2022 2:28 PM
W
PRF
strain
PRF
pressure
D
Dr. Vikas Sharma
03:16
1:12:26
100%
19°C
Haze
ENG
IN
11:24 PM
3/2/2022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Physical Quantities
W
strain
PRF
pressure
Vout
=0
ΔR/R / ε = ∂ρ / ρε + (1+2ν)
Material property
geometrical property
D
Dr. Vikas Sharma
07:23
1:12:26
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19°C
Haze
ENG
IN
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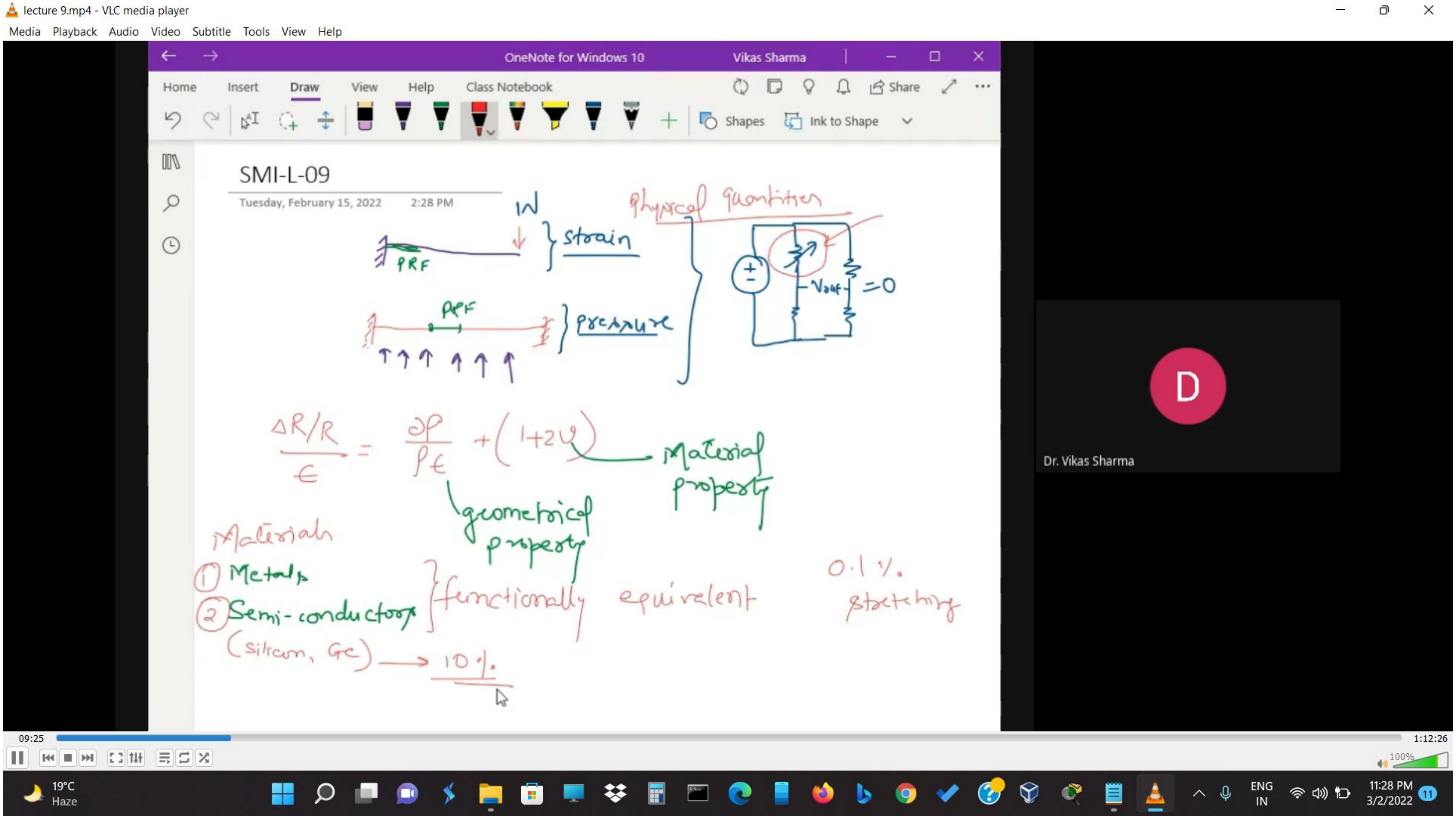
3/2/2022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SMI-L-09
Tuesday, February 15, 2022 2:28 PM
Physical Quantities
W
strain
PRF
PRF
pressure
Vout = 0
ΔR/R / ε = ∂ρ/ρε + (1+2ν)
Material property
geometrical property
Materials
① Metals
② Semi-conductors
(silicon, Ge) → 10%
functionally equivalent
0.1%
stretching
D
Dr. Vikas Sharma
09:25
1:12:26
100%
19°C
Haze
ENG
IN
11:28 PM
3/2/2022

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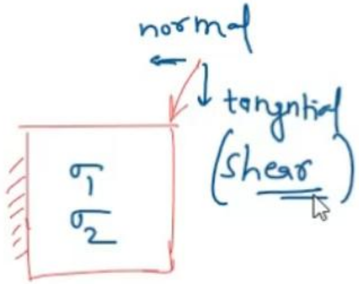
(2) Semi-conductors (functionally equivalent — stretching

(silicon, Ge) $\longrightarrow$ 10 %

$$\frac{\Delta R}{R} = \frac{G}{E}\sigma = \pi\sigma$$

$$\frac{\Delta \rho}{\rho} = \pi_1\sigma_1 + \pi_2\sigma_2$$



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12:39 / 1:12:26

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Shapes Ink to Shape

SMI-L-09

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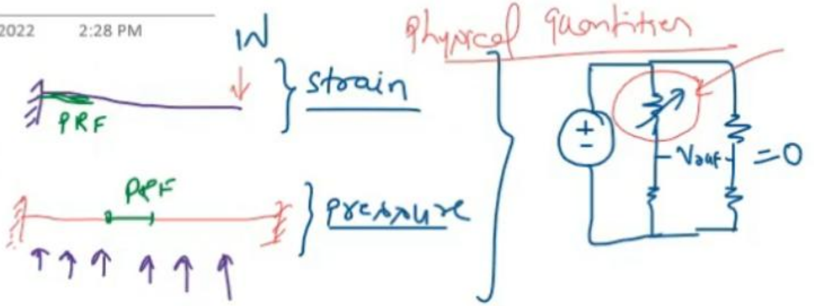
thickness (microns)



$$\frac{\Delta R/R}{\epsilon} = \frac{\partial \rho}{\rho \epsilon} + (1+2\nu)$$

material property

geometrical property

Materials

(1) Metals

(2) Semi-conductors (silicon, Ge) $\longrightarrow$ 10%

functionally equivalent

0.1% stretching

normal

D

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14:39 1:12:26

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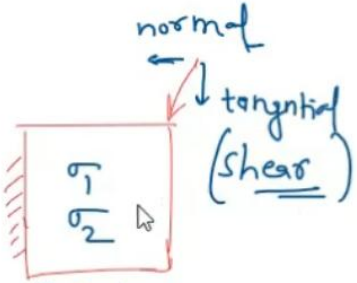
② Semi-conductors (functionally equivalent stretching
(silicon, Ge) ⟶ 10%.

$$\frac{\Delta R}{R} = \frac{G}{E}\sigma = \pi\sigma$$



2-D loading behaviour

$$\frac{\Delta\rho}{\rho} = \pi_1\sigma_1 + \pi_2\sigma_2$$

$$= \pi_l\sigma_l + \pi_r\sigma_r$$

longitudinal radial

r, θ, z
r

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Shapes Ink to Shape

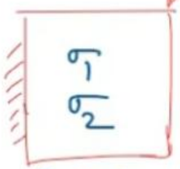
(2) Semi-conductors {functionally equivalent — stretching

(silicon, Ge) $\longrightarrow$ 10 %

$$\frac{\Delta R}{R} = \frac{G}{E}\sigma = \pi\sigma \Big\} \text{ linear}$$

normal

tangential (shear)

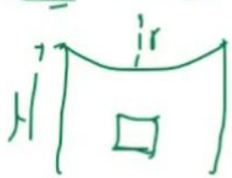


2-D loading behaviour

$$\frac{\Delta \rho}{\rho} = \pi_1\sigma_1 + \pi_2\sigma_2 \Big\} \text{ linear}$$

$$= \pi_l\sigma_l + \pi_r\sigma_r$$

longitudinal radial



r, θ, z

r

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18:01 — 1:12:26

19°C Haze — ENG IN — 11:34 PM 3/2/2022

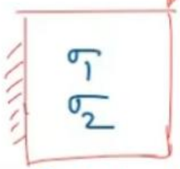
② Semi-conductors (silicon, Ge) → 10% { functionally equivalent

stretching

$$\frac{\Delta R}{R} = \frac{G}{E}\sigma = \pi\sigma \quad \text{linear}$$

normal

tangential (shear)



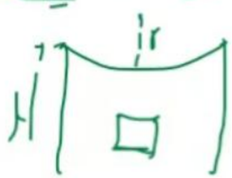
$$\frac{\Delta\rho}{\rho} = \pi_1\sigma_1 + \pi_2\sigma_2 \quad \text{linear}$$

$$= \pi_l\sigma_l + \pi_r\sigma_r$$

2-D loading behavioural

longitudinal radial

nonlinearity
- piezoresistive
- circuit
- structural



r, θ, z

r

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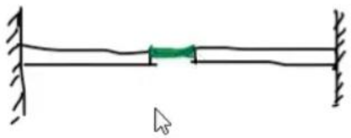
Shapes Ink to Shape

↳ structural]

8, θ, z

γ

Modelling & Development of Piezo-resistive Pressure sensor



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Shapes Ink to Shape

→ piezo-resistive
→ circuit } application
→ structural

cylindrical

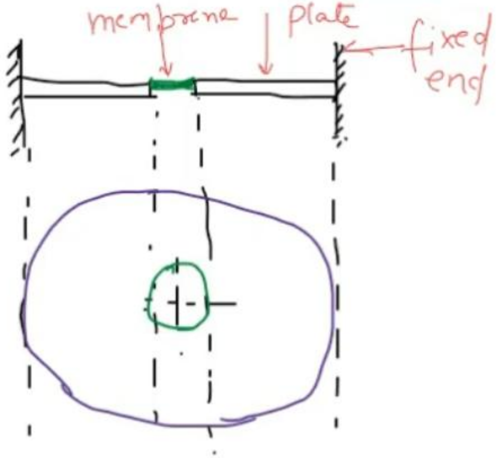
r, θ, z

r

Modelling & Development of Piezo-resistive Pressure sensor

(1) Voltage out → sensitivity of the sensor

(2) Amount of strains



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29:03 1:12:26

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Shapes Ink to Shape

→ piezo-resistive
→ circuit
→ structural

} application

cylindrical

r, θ, z

r

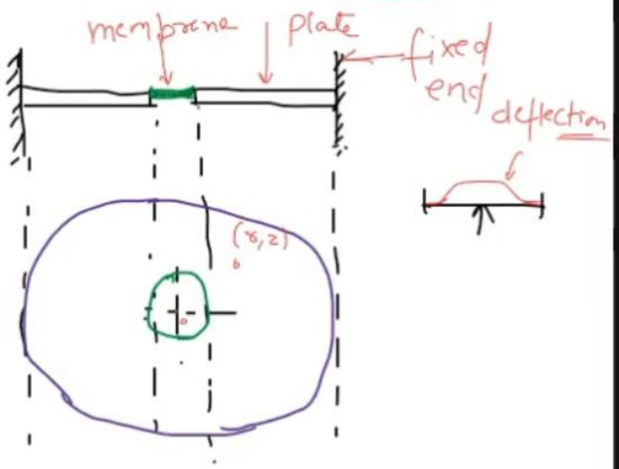
Modelling & Development of Piezo-resistive Pressure sensor

(1) Voltage out → Sensitivity of the sensor

(2) Amount of strains

thickness of plate (h)

deflection of plate (δ)



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33:18 1:12:26

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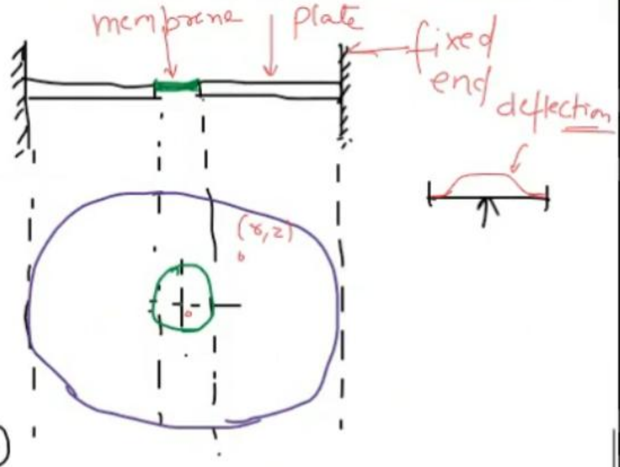
(1) Voltage out → Sensitivity of the sensor

(2) Amount of strains



thickness of plate (h)

deflection of plate (δ)

uniformly distributed pressure (p)

Assumption

$\delta << h/5$

a differential eqn to describe the deflection / elastic behaviour

$$\nabla^4 \delta = \frac{P}{K} \qquad \left\{ K = \frac{Eh^3}{12(1-\nu^2)} \right.$$

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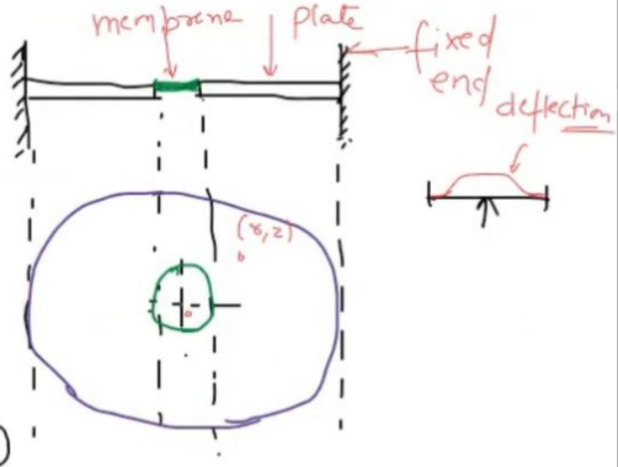
(1) Voltage out → Sensitivity of the sensor

(2) Amount of strains



thickness of plate (h)

deflection of plate (δ)

uniformly distributed pressure (p)

Assumption

$\delta << h/5$

a differential eqn to describe the deflection / elastic behaviour

$\frac{D^4}{dt}$

$$\nabla^4 \delta = \frac{p}{k}$$

$$\left\{ k = \frac{Eh^3}{12(1-\nu^2)} \right.$$

stiffness

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36:09 1:12:26

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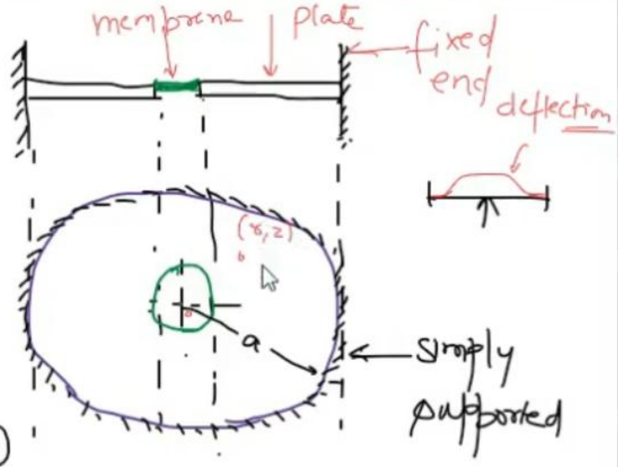
(1) Voltage out → Sensitivity of the sensor

(2) Amount of strains



thickness of plate (h)

deflection of plate (δ)

uniformly distributed pressure (p)

Assumption

$\delta << h/5$

a differential eqn to describe the deflection / elastic behaviour

$$\nabla^4 \delta = \frac{p}{K} \qquad \left\{ K = \frac{Eh^3}{12(1-\nu^2)} \right.$$

Stiffness

$$\delta = \frac{p(a^2-r^2)}{\ldots}\left[\left(\frac{5+\nu}{\ldots}\right)(a^2-r^2)\right]$$

D

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38:29 1:12:26

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Shapes Ink to Shape

Assumption

$\delta << h/5$

a differential eqn to describe the deflection / elastic behaviour

$$\nabla^4 \delta = \frac{P}{K}$$

$$\left\{ K = \frac{Eh^3}{12(1-\nu^2)} \right.$$

Stiffness

$$\delta = \frac{P(a^2 - r^2)}{64K}\left[\left(\frac{5+\nu}{1+\nu}\right)(a^2 - r^2)\right]$$

D

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38:56 1:12:26

100%

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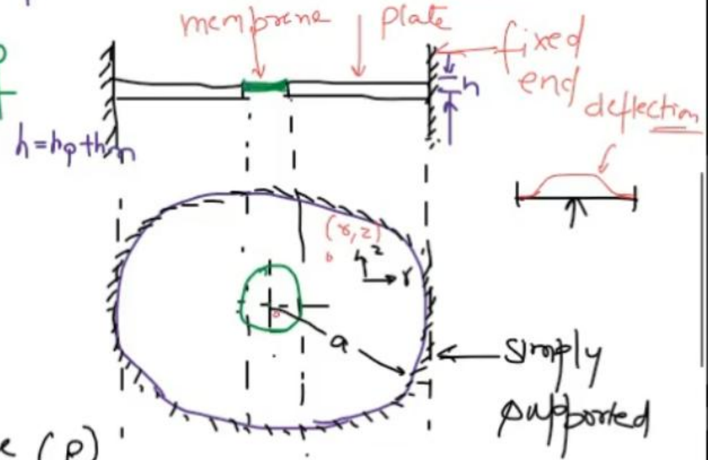
Modelling & Development of Piezo-resistive Pressure sensor

(1) Voltage out → Sensitivity of the sensor

(2) Amount of strains



thickness of plate (h)

deflection of plate (δ)

uniformly distributed pressure (p)

Assumption

$\delta << h/5$

a differential eq^n to describe the deflection / elastic behaviour

$$\nabla^4 \delta = \frac{p}{k} \qquad \left\{ k = \frac{Eh^3}{12(1-\nu^2)} \right.$$

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Shapes Ink to Shape

strain → radial

strain → tangential

Radial strain

$$\epsilon_r(r,z) = -\frac{kz}{Eh^3/12}\left(\frac{d^2\delta}{dr^2} + \frac{\nu}{r}\frac{d\delta}{dr}\right)$$

$$\epsilon_r(r,z) = \frac{3}{8}\left[\frac{pa^2(h_p-h_m)(3+\nu)}{E}\right.$$

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42:51 1:12:26

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Shapes Ink to Shape

Strain → radial, → tangential

Radial strain

$$\epsilon_r(r,z) = -\frac{kz}{Eh^3/12}\left(\frac{d^2\delta}{dr^2} + \frac{\upsilon}{r}\frac{d\delta}{dr}\right)$$

$$\epsilon_r(r,z) = \boxed{\frac{3}{8}\left[\frac{pa^2(h_p-h_m)(3+\upsilon)}{E(h_p+h_m)^3}\right]}\left[1-\frac{r^2}{a^2}\right]$$

$$\epsilon_t = \boxed{\frac{3}{8}\left[\frac{pa^2(h_p-h_m)(3+\upsilon)}{E(h_p+h_m)^3}\right]}\left[1-\left(\frac{3\upsilon+1}{3+\upsilon}\right)\left(\frac{r^2}{a^2}\right)\right]$$

ϵ_0 → max. strain acting at the centre of the circular plate

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45:34 1:12:26

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Shapes Ink to Shape

Strain → radial
→ tangential

Radial strain

$$\epsilon_r(r,z) = -\frac{kz}{Eh^3/12}\left(\frac{d^2\delta}{dr^2} + \frac{\nu}{r}\frac{d\delta}{dr}\right)$$

$$\epsilon_r(r,z) = \boxed{\frac{3}{8}\left[\frac{pa^2(h_p-h_m)(3+\nu)}{E(h_p+h_m)^3}\right]}\left[1-\frac{r^2}{a^2}\right]$$

$$\epsilon_t = \boxed{\frac{3}{8}\left[\frac{pa^2(h_p-h_m)(3+\nu)}{E(h_p+h_m)^3}\right]}\left[1-\left(\frac{3\nu+1}{3+\nu}\right)\left(\frac{r^2}{a^2}\right)\right]$$

$\epsilon_0 \rightarrow$ max. strain acting at the centre of the circular plate

D

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47:45 1:12:26

100%

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Shapes Ink to Shape

$\epsilon_0 \rightarrow$ max. strain acting at the centre of the circular plate

$$P/A = \sigma = E\epsilon$$

$$P/\epsilon = E \times A = \frac{\pi}{4} E r^2$$

$$P/\epsilon = r^2$$

Pressure induced strains are f^n of radius (circular)

$$\bar{\epsilon}_r = \frac{\int_{r_1}^{r_0} \epsilon_r(r)\,dr}{\int_{r_1}^{r_0} dr}$$

D

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49:44 1:12:26

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Shapes Ink to Shape

$$P/A = \sigma = E\epsilon$$

$$P/\epsilon = E \times A = \frac{\pi}{4} E r^2$$

$$P/\epsilon = r^2$$

Response induced strains are f^n of radius (circular)

$$\bar{\epsilon}_r = \frac{\int_{r_1}^{r_0} \epsilon_r(r)\,dr}{\int_{r_1}^{r_0} dr}$$

Mean radial strain

$$= \epsilon_0$$

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50:08 1:12:26

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Pressure induced strains are f^n of radius (circular)

$$\bar{\epsilon}_r = \frac{\int_{r_1}^{r_0} \epsilon_r(r)\,dr}{\int_{r_1}^{r_0} dr}$$

Mean radial strain

$$= \epsilon_0 \left[1 - \frac{1}{3a^2}\left(\frac{r_0^3 - r_1^3}{r_0 - r_1}\right)\right]$$

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51:02 — 1:12:26

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Pressure induced strains are f^n of radius (circular)

$$\bar{\epsilon}_r = \frac{\int_{r_1}^{r_0} \epsilon_r(r)\,dr}{\int_{r_1}^{r_0} dr}$$

Mean radial strain

$$= \epsilon_0 \left[1 - \frac{1}{3a^2} \left(\frac{r_0^3 - r_1^3}{r_0 - r_1} \right) \right]$$

Mean tangential strain

$$\bar{\epsilon}_t = \epsilon_0 \left[1 - \frac{1}{3a^2} \left(\frac{3\nu + 1}{3 + \nu} \right) \left(\frac{\rho_0^3 - \rho_i^3}{\rho_0 - \rho_i} \right) \right]$$

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51:55 1:12:26

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$$\bar{\epsilon}_t = \epsilon_o \left[1 - \frac{1}{3a^2} \left(\frac{3\nu+1}{3+\nu} \right) \left(\frac{\rho_o^3 - \rho_i^3}{\rho_o - \rho_i} \right) \right]$$

$$\text{Gauge factor} = \frac{\Delta R / R}{\epsilon}$$

$$\frac{\Delta R}{R} = \text{Gauge factor} \times \epsilon$$

$$\frac{\Delta R}{R}_r = G\left(\bar{\epsilon}_r + \epsilon_{temp}\right) \qquad \frac{\Delta R}{R}_t = G\left(\bar{\epsilon}_t + \epsilon_{temp}\right)$$

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55:03 1:12:26

100%

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$$V_{out} = \frac{V_s\left(\frac{\Delta R_r}{R} - \frac{\Delta R_t}{R}\right)}{2 + \frac{\Delta R_r}{R} + \frac{\Delta R_t}{R}}$$

$$\frac{\Delta R}{R} \begin{cases} = 1 \\ < 1 \\ > 1 \end{cases} \qquad \frac{\Delta R_r}{R} \ll 1$$

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$$2 + \frac{\Delta R_r}{R} + \frac{\Delta R_t}{R}$$

$$\frac{\Delta R}{R} \begin{cases} = 1 \\ < 1 \\ > 1 \end{cases} \qquad \frac{\Delta R_{r,t}}{R} << 1$$

$$V_{out} = \frac{V_s}{2} \cdot G \left(\bar{\epsilon}_r - \bar{\epsilon}_t\right)$$

$$V_{out} = \frac{G}{16} \frac{(h_p - h_m)(3+\nu)}{E(h_p + h_m)^3} \times \left[\frac{3\nu+1}{3+\nu} \cdot \left(\frac{\rho_0^3 - \rho_1^3}{\rho_0 - \rho_1}\right) - \left(\frac{r_0^3 - r_1^3}{r_0 - r_1}\right)\right] P$$

D

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$$\frac{\Delta R}{R} \begin{cases} <1 \\ >1 \end{cases} \qquad \frac{\Delta R}{R} \ll 1$$

$$V_{out} = \frac{V_s}{2} \cdot G \left(\bar{\epsilon}_r - \bar{\epsilon}_t \right)$$

pressure

$$V_{out} = \frac{G}{16} \frac{(h_p - h_m)(3+\upsilon)}{E(h_p + h_m)^3} \times \left[\frac{3\upsilon+1}{3+\upsilon} \cdot \left(\frac{\rho_0^3 - \rho_1^3}{\rho_0 - \rho_1} \right) - \left(\frac{r_0^3 - r_1^3}{r_0 - r_1} \right) \right] P$$

Sensitivity of a P.R. based Pressure sensor (P)

$$S = \frac{1}{V_s} \frac{d}{dP} V_{out}$$

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1:01:24 1:12:26

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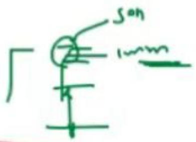
Sensitivity of a P.R. based Pressure sensor (P)

$$S = \frac{1}{V_s}\frac{d}{dP}V_{out}$$



$$\boxed{S = \frac{G}{16}\frac{(h_p - h_m)(3+\upsilon)}{E(h_p+h_m)^3} \times \left[\left(\frac{3\upsilon+1}{3+\upsilon}\right)\left(\frac{\rho_0^3 - \rho_1^3}{\rho_0 - \rho_1}\right) - \frac{r_0^3 - r_1^3}{r_0 - r_1}\right]}$$

Material → flexible

↳ Elastic modulus (low) ↓

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Shapes Ink to Shape

$$\text{Gauge factor} = \frac{\Delta R / R}{\epsilon}$$

$$\frac{\Delta R}{R} = \text{Gauge factor} \times \epsilon$$

$$\frac{\Delta R_r}{R} = G(\bar{\epsilon}_r + \epsilon_{temp}) \qquad \frac{\Delta R_t}{R} = G(\bar{\epsilon}_t + \epsilon_{temp})$$

doping

n, p

silicon

G_E

Semicond

$$V_{out} = \frac{V_s \left(\frac{\Delta R_r}{R} - \frac{\Delta R_t}{R} \right)}{2 + \frac{\Delta R_r}{R} + \frac{\Delta R_t}{R}}$$

$$\frac{\Delta R}{R} \begin{cases} = 1 \\ < 1 \end{cases} \qquad \frac{\Delta R_{r,t}}{R} << 1$$

Dr. Vikas Sharma

1:11:06 1:12:26

100%

18°C Haze ENG IN 12:01 AM 3/3/2022