20. Microwave Engineering

Dec. 12, 2019

Microwave engineering

Microwave frequencies are a few GHz

The wavelength is smaller than the circuit

Losses in metals increase with increasing frequency

Losses in dielectrics increase with increasing frequency

There is a characteristic length scale called the skin depth which tells us how far into a metal fields penetrate before they are reflected out.

Skin depth ωτ << 1

$$\sigma(\omega) = ne\mu\left(\frac{1-i\omega\tau}{1+\omega^2\tau^2}\right) \approx ne\mu = \sigma_0$$

$\omega\tau << 1$

Ohm's law

$$\vec{J} = \sigma_0 \vec{E}$$

Take the curl

$$\frac{1}{\sigma_0}\nabla\times\vec{J} = \nabla\times\vec{E} = -\frac{d\vec{B}}{dt}$$

Faraday's law

$$\nabla\times\vec{B} = \mu_0\vec{J}$$

Ampere's law

$$\frac{1}{\sigma_0\mu_0}\nabla\times\nabla\times\vec{B} = -\frac{d\vec{B}}{dt}$$

Vector identity

$$\nabla\times\nabla\times\vec{B} = \nabla\left(\overset{0}{\cancel{\nabla\cdot\vec{B}}}\right) - \nabla^2\vec{B}$$

$$\frac{1}{\sigma_0\mu_0}\nabla^2\vec{B} = \frac{d\vec{B}}{dt}$$

Skin depth

$$\frac{1}{\sigma_0\mu_0}\nabla^2\vec{B} = \frac{d\vec{B}}{dt}$$

Assume harmonic dependence $B_0 e^{i(kx-\omega t)}$

$$\frac{k^2}{\sigma_0\mu_0} = i\omega$$

$$k = \sqrt{i\omega\sigma_0\mu_0} = \sqrt{\frac{\omega\sigma_0\mu_0}{2}} + i\sqrt{\frac{\omega\sigma_0\mu_0}{2}}$$

Exponential decay

Skin depth $\delta = \sqrt{\frac{2}{\mu_0\sigma_0\omega}}$

Light $\omega < \omega_p$ is reflected out of a metal. The waves penetrate a length δ.

Skin depth

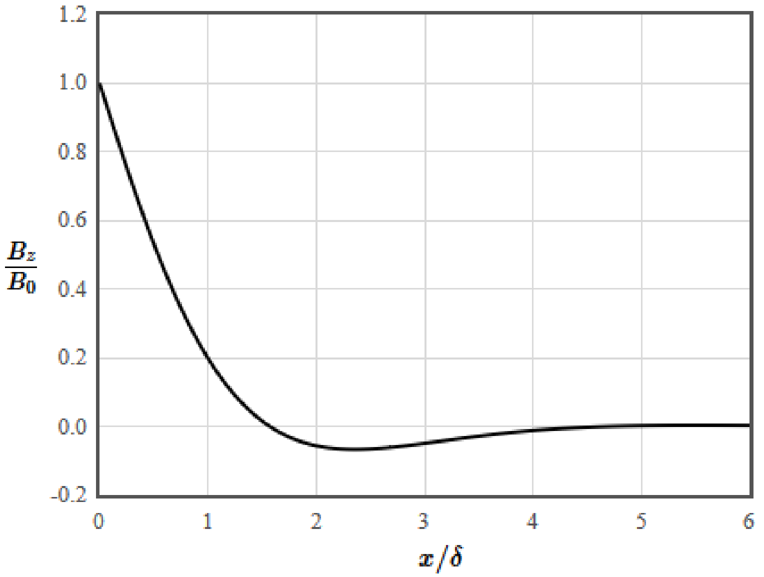
$$\vec{B} = B_0 e^{-x/\delta} e^{i(x/\delta - \omega t)} \hat{z}$$

$$\vec{J} = \frac{1}{\mu_0} \nabla \times \vec{B} = \vec{B} = \frac{B_0(1-i)}{\mu_0 \delta} e^{-x/\delta} e^{i(x/\delta - \omega t)} \hat{y}$$

$$1 - i = \sqrt{2} e^{-i\pi/4}$$

$$\vec{J} = \frac{\sqrt{2} B_0}{\mu_0 \delta} e^{-x/\delta} e^{i(x/\delta - \omega t - \pi/4)} \hat{y}$$

$$\vec{E} = \frac{\vec{J}}{\sigma_0} = \frac{\sqrt{2} B_0}{\mu_0 \delta \sigma_0} e^{-x/\delta} e^{i(x/\delta - \omega t - \pi/4)} \hat{y}$$



The electric field lags behind the magnetic field by 45 degrees.

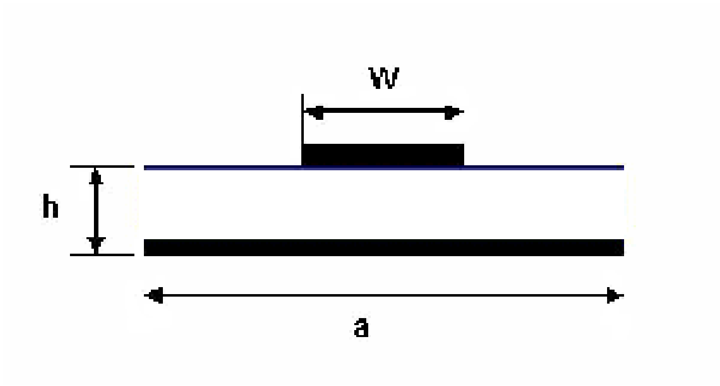
Surface resistance

At low frequencies: $R = \frac{\rho \ell}{wt} = \frac{\ell}{\sigma_0 wt}$

When $\delta < t$: $R = \frac{\ell}{\sigma_0 w \delta}$

for $\ell = w$

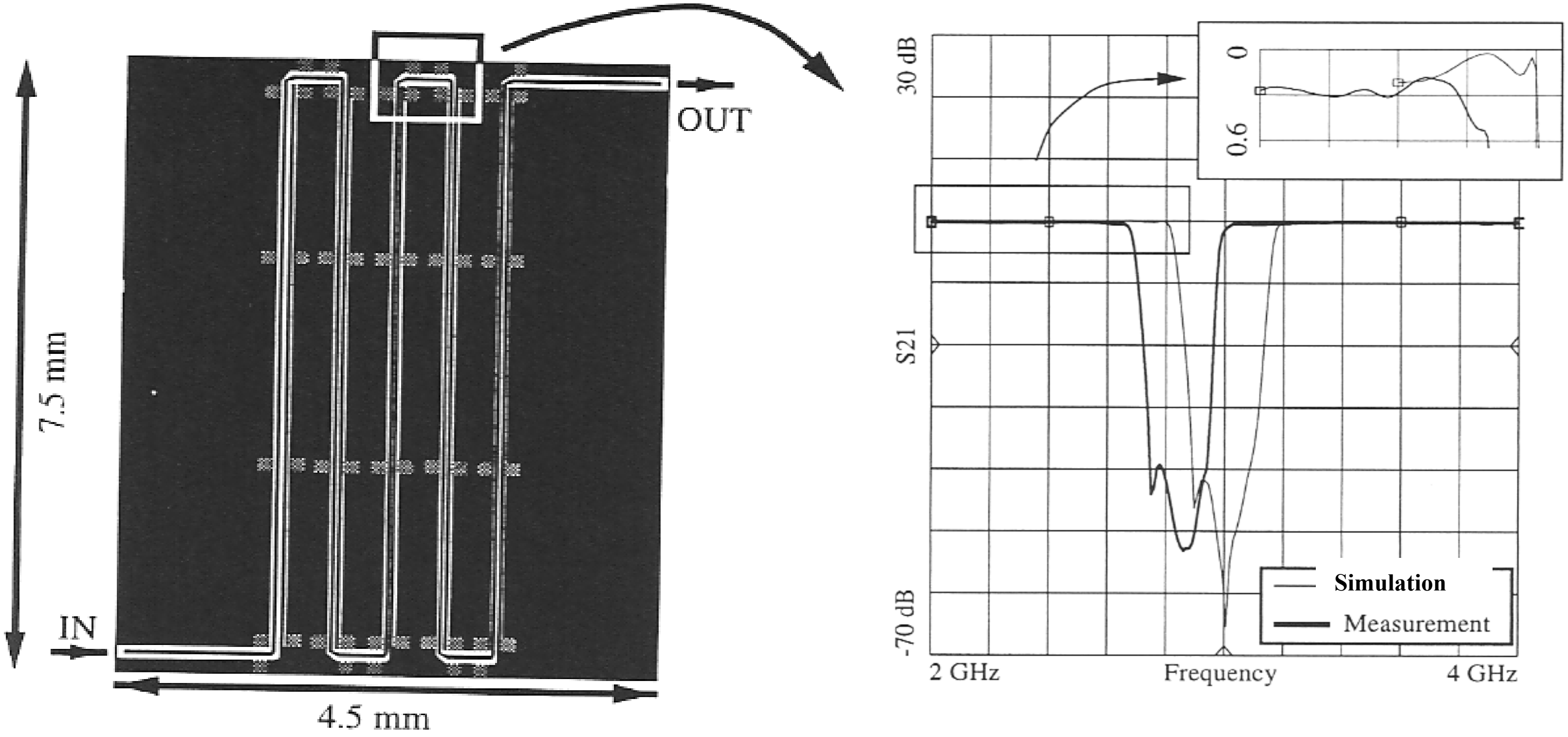
$$R_s = \frac{1}{\sigma_0 \delta} \propto \sqrt{\omega}$$



Complex signal processing at high frequencies > 1 GHz is difficult because the losses increase with frequency.

Usually you mix down to a lower frequency as soon as possible.

Superconducting filter



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Multiferroics

simultaneously ferroelectric and ferromagnetic

$BiFeO_3$

If two magnetic sublattices have different charge, changing the magnetic field can change the polarization and changing the electric field can change the magnetization.

Nitinol

Ni Ti alloy

Shape memory: If it is bent below a certain transition temperature and then heated above that temperature, it returns to its original shape.

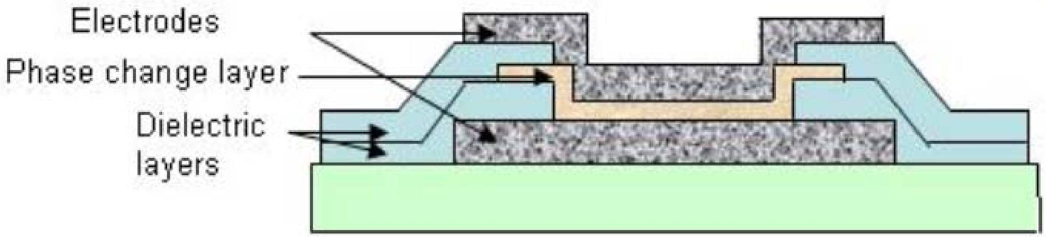
Superelasticity: Just above the transition temperature, the material exhibits elasticity 10-30 times that of an ordinary metal.

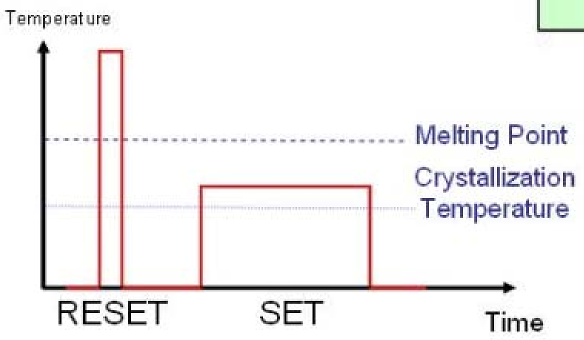
Martisite - Austinite

Phase change memory

Phase-change memory (PRAM) uses chalcogenide materials. These can be switched between a low resistance crystalline state and a high resistance amorphous state.

GeSbTe is melted by a laser in rewritable DVDs and by a current in PRAM.

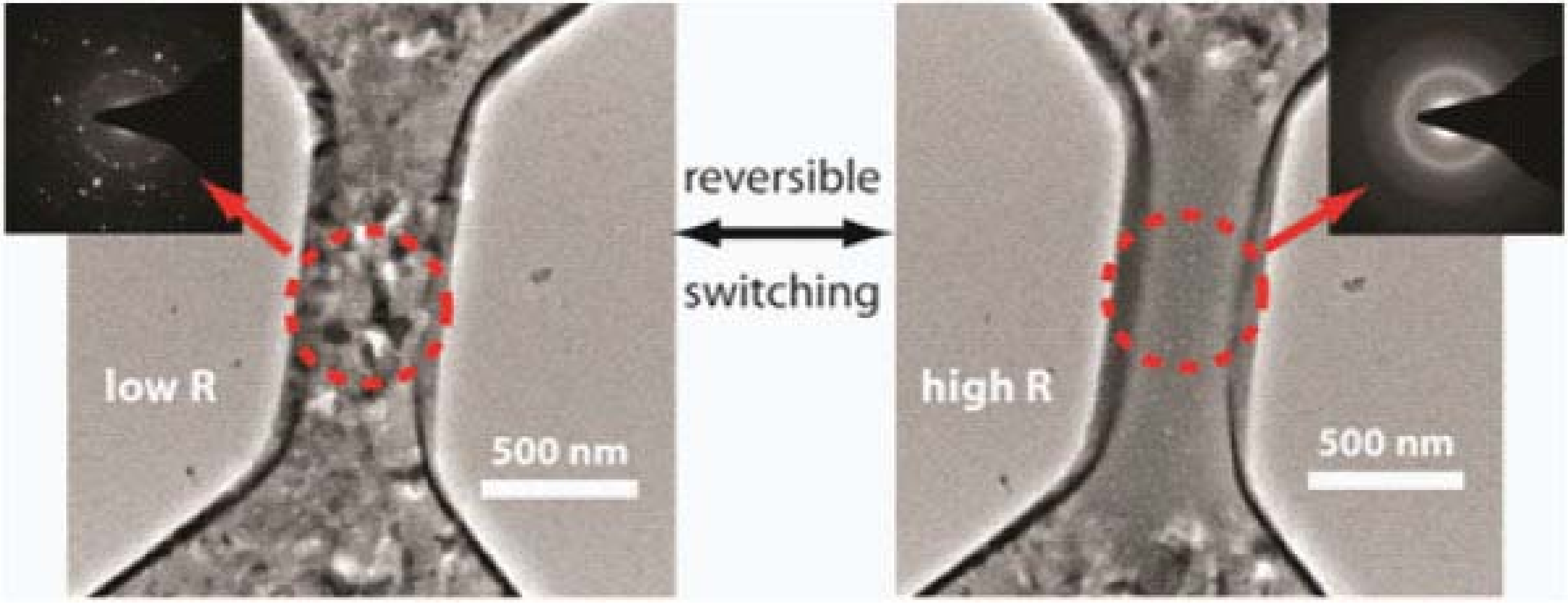




nonvolatile

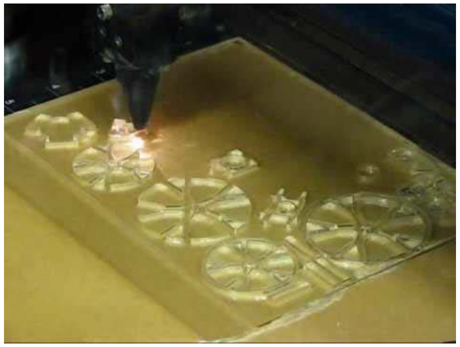
Phase change material

Electron diffraction in a TEM of a GeSbTe alloy.



http://web.stanford.edu/group/cui_group/research.htm

Laser-cutting/engraving



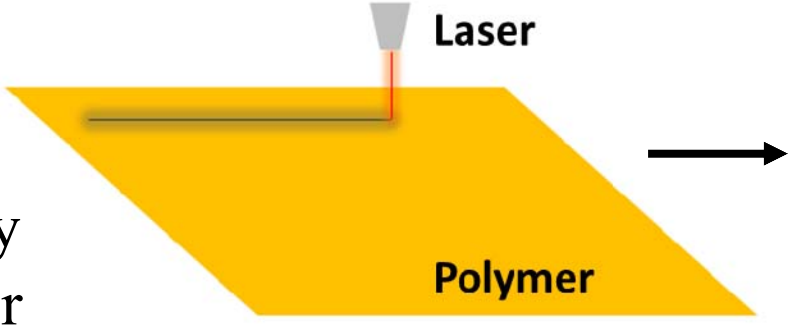
CUTTING AND/OR ENGRAVING of Plastic, Elastomers, Glass, Paper, Bio-derived materials, Metals, etc.

VLS 2.30 Universal Laser System

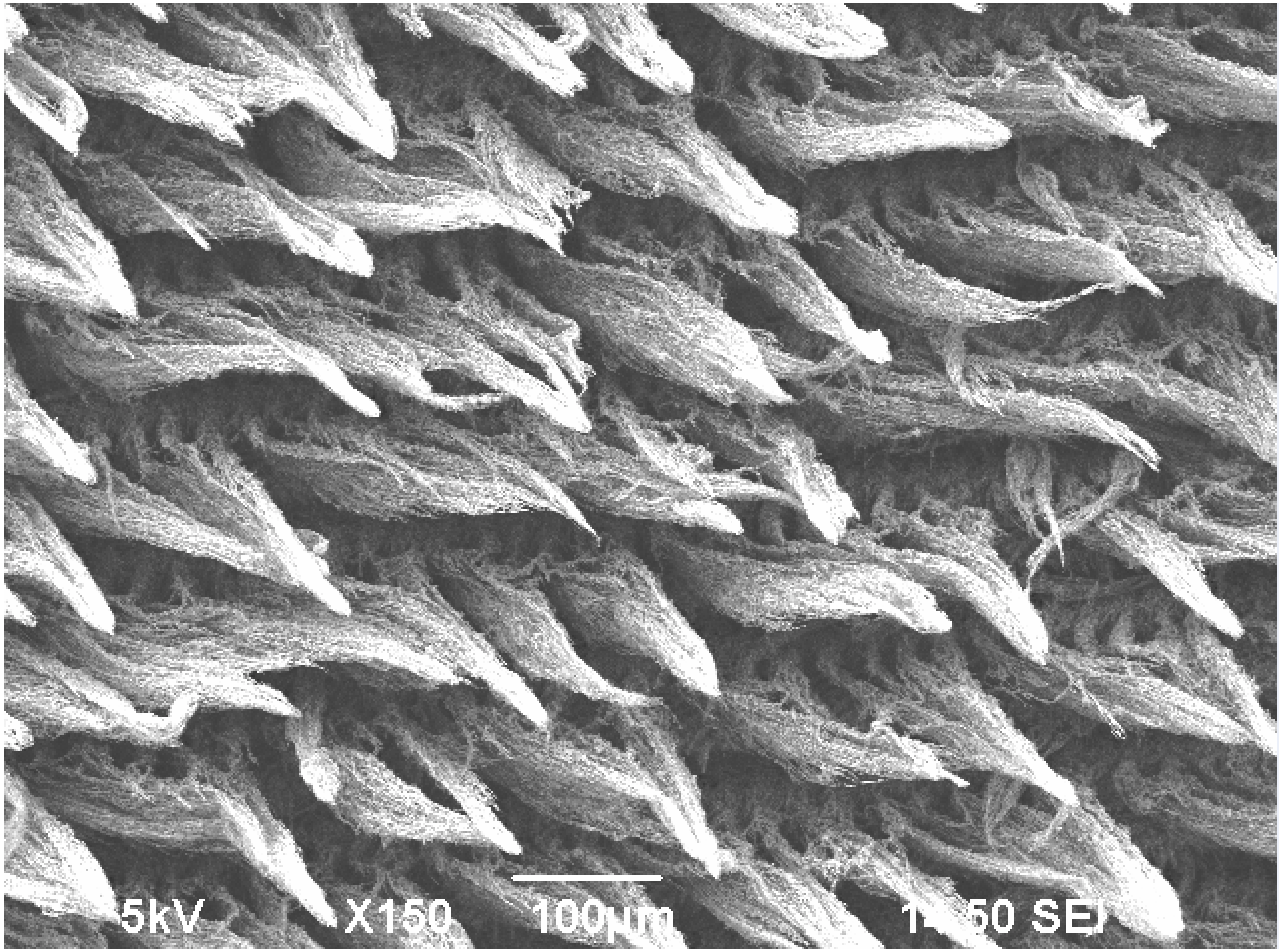
- laser source: 30 W CO_2 (wavelength 10.6 μm)
- equipped with: 2.0” lens (beam size at focus ~120 μm)

  High Power Density Focusing Optics (beam size at focus ~30 μm)
- cutting table dimensions: 406 x 305 mm

Patterning of conductive Laser Induced Graphene (photothermal process by laser scribing on polymer



laser-induced pyrolysis of polymers



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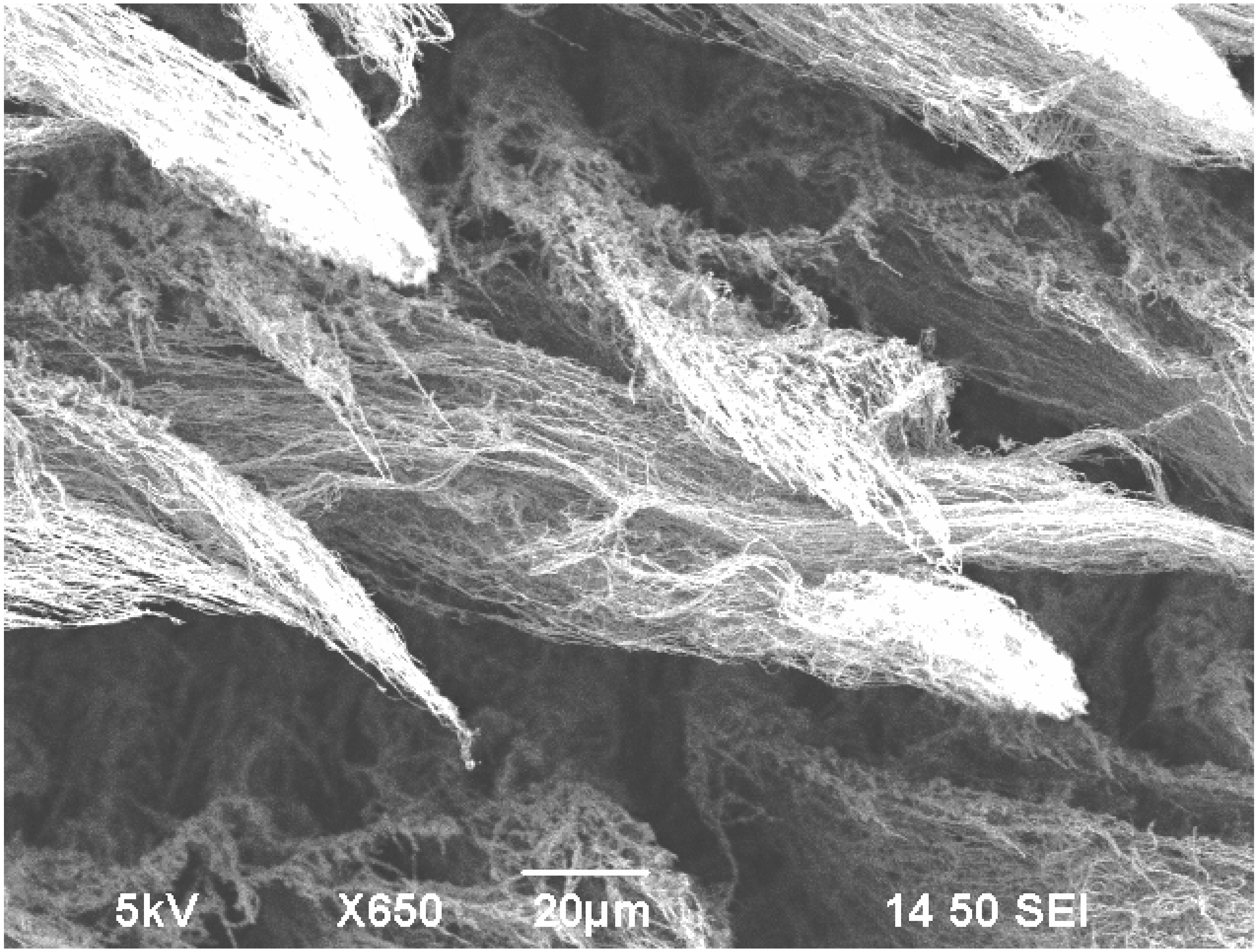

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