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ASSIGNMENT

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Declaration Sheet			
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Course Code	BSC102B		
Course Title	Engineering Physics		
Course Date		to	
Course Leader			

Declaration

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Signature of the Student		Date	
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Signature of the Course Leader and date	Signature of the Reviewer and date

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<u>Question No. 1</u>

<u>Solution to Question No. 1 part A:</u>

A.1 Principle of PCFs and GFO with schematic diagram:

GFO:

A fiber optic is composed of three general components. The light signal is transmitted down the central portion called the core, which is composed of silica. The core is surrounded by a second layer called the cladding. The buffer coating protects the internal structure from damage.

The light wave travels the length of the fiber through the core by reflecting from the core-cladding interface. This effect is called total internal reflection

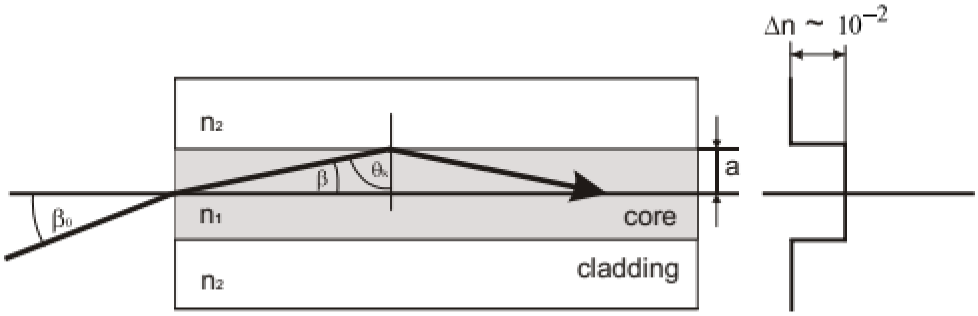

Figure 1: Schematic diagram of standard step index optical fiber.

PCFs:

The newest approach to solving the problem of signal degradation came on the heals of a prediction in the early 1990's by Eli Yablonovitch. He predicted that certain three-dimensionally periodic photonic crystal structures contained complete photonic bandgaps. The presence of these bandgaps meant that for certain frequency range there were no propagating modes through the material. This means that if used as a cladding material, the signal would not be able to propagate into and through the cladding. This prediction opened the field of fiber optic manufacturing to the possibility of producing a core-cladding interface that produces total internal reflection.

These three dimensionally periodic crystal structures are however incredibly complicated to fabricate, requiring the correct refractive index contrast, pitch and structural integrity to achieve the desired interface behavior. The solution was to create a two-dimensionally periodic material that is periodic in the plane perpendicular to the axis of the fiber but constant along its length. This new technique in fiber development creates optically an excellent approximation of this 2-D structure by imbedding microscopic holes running the length of the cladding parallel to the core axis as shown in Figure 3.

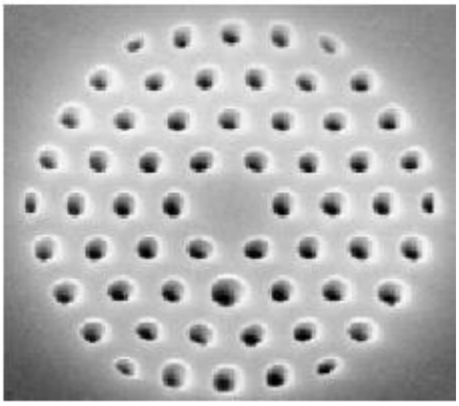

Figure 2: Photonic Crystal Fiber cross-section

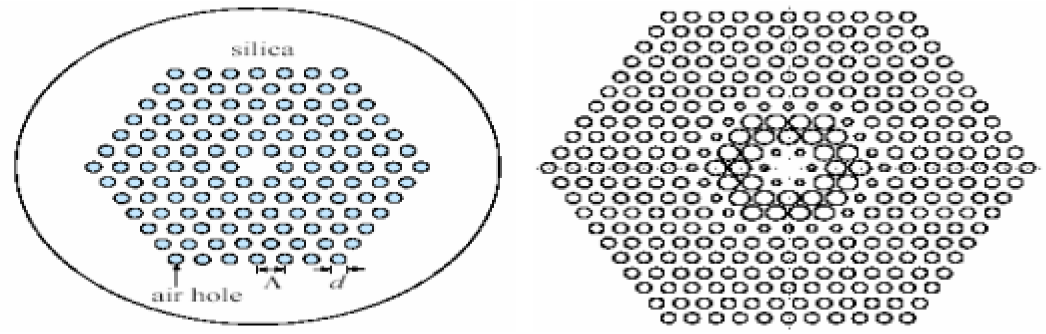

Figure 3: Differing Photonic Crystal Fiber cross-sections

A.2 Light guidance mechanism in PCFs and GFO:

GFO:

Optical communication over the years has relied on conventional optical fibers whose main guiding mechanism is essentially the phenomenon of total internal reflection. Light is trapped in an inner transparent solid core wrapped with a second material (cladding) of higher index of refraction

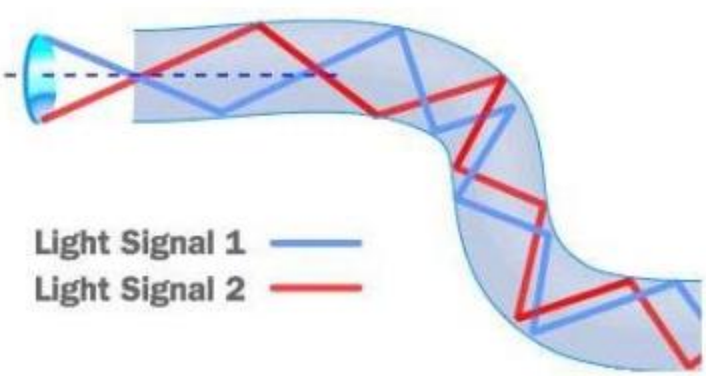

Figure 4: Total Internal Reflection Signal Transmission

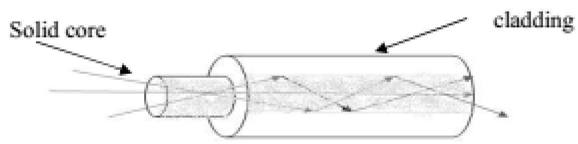

Figure 5: A Typical Conventional Optical Fiber

PCF:

Photonic crystal fibers (PCF) usually fall into two categories:

High – index guiding fibers and photonic bandgap fibers. The first kind of PCFs are more similar to conventional optical fibers because light is confined in a solid core by exploiting a “special” kind of total internal reflection mechanism. This guiding principle is different from that of conventional optical fibers in that the refractive index of the cladding is not constant but varies with wavelength.

We are actually concerned with the later type of PCFs which employs the PBG effect. A photonic crystal designed with the ability to forbid the propagation of electromagnetic waves in certain frequency ranges (forming band gaps) is known as a photonic bandgap (PBG) material. The phenomenon of forming band gaps in a photonic crystals is known as the PBG effect. Optical fibers fabricated to employ the PBG effect are known as Photonic bandgap fibers (PGBF).

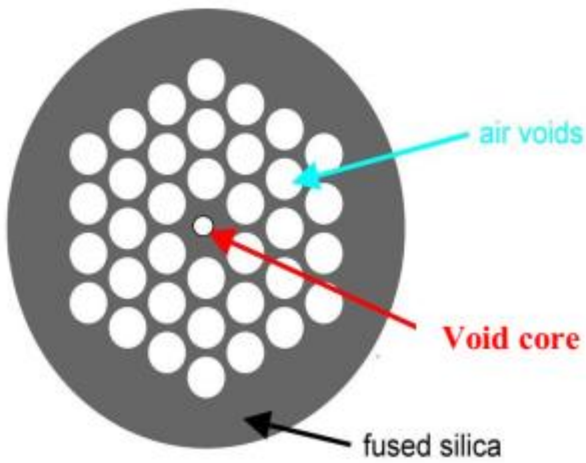

Figure 6: Cross Section Bandgap – guided fiber

Once light is induced to travel along the fiber, it really has nowhere to go, since the frequency of the guided mode lies within the photonic bandgap, the mode is forbidden to escape.

A.3 Advantages and disadvantages of PCFs and GFO:

These fibers, known as single-mode, do have significant disadvantages. First the diameter of the fiber is significantly smaller, about 9 µm resulting in a weaker fiber more susceptible to physical damage. The small diameter also introduces problems in coupling these fibers to light sources and in aligning the junction properly so that the fiber is infused with light. These fibers transmit infrared laser light (λ=1,300 - 1,550 nanometers).

The other major cause of loss through the fiber comes from the imperfections in the core or cladding and the nature of their interface. In attempting to increase the transmission effectiveness a new area of research has begun to engineer new cladding materials that enhance the nature of that interface.

In conventional fiber–optic cables, along a tight bend (curve) the angle of incidence is too large for total internal reflection to occur, so light escapes at the corners and is lost. PBG fibers continue to confine light around tight corners since they do not depend on total internal reflection.

The hollow (gas filled) transmission path in PBG fibers offer a much lower loss high power channel than glass which is highly limited by Rayleigh scattering. Though the lowest lost figure of PBG fibers is still very high compared to typical standard single – mode conventional optical fibers. The main effects causing the loss in hollow core PBG fibers are the width of the bandgap and the confinement loss due to the finite number of air holes. Thus the design and fabrication of PBG fibers that exhibit the largest bandgap is of profound importance. An example of such ingenious designs is the triangular lattice – consisting of a circular array of air holes packed in a triangular arrangement.

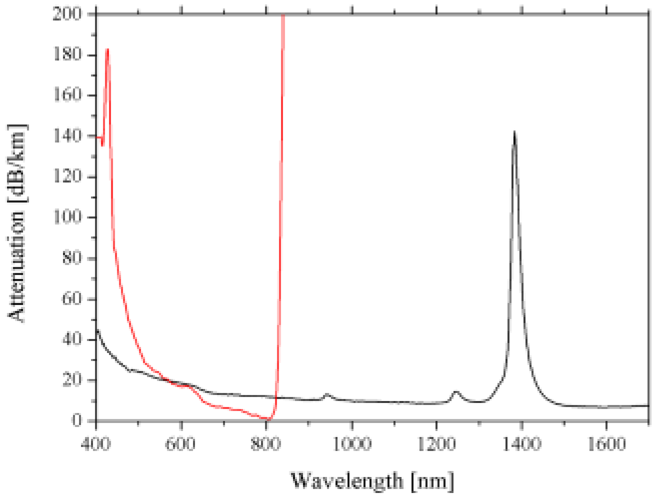

Figure 7: Attenuation spectral of conventional optical fiber(red) and PBG fiber(black)

PBG fibers have a significantly larger optical bandwidth than single mode conventional optical fibers for the same mode–field diameter. In conventional fibers, the single–mode optical bandwidth is limited by higher–order mode cutoff at short wavelengths and micro–bend loss at long wavelengths.

A.3 Stance taken with justification:

Through photonic bandgap manipulation cladding material can be engineered that does not support any modes for certain frequencies, creating total internal reflection. The engineerable birefringence allows for relatively high refractive index contrasts. This allows a mode to be confined in a core much smaller than previously possible, less than the wavelength of the light. The current performance of single-mode optical fibers results from many years of intensive research. There appears to be no reason why the losses in Photonic Crystal Fibers cannot be reduced to or below that of standard optical fibers. Similar development effort could lead to explosive growth in photonic crystal fiber technology over the coming years. The optical properties of PBG fibers presented confirm the superiority of this artificial material as the optical waveguide for next generation optical communication. The fabrication challenges and the still relatively high transmission loss of PBG fibers open up avenues for more fundamental research.

Question No. 2

Solution to Question No. 1 part B:

$L = 20 + N + X = 20 + 59 + 3 = 82\ cm = 0.82\ m$

$d = 3\ cm = 0.03\ m$

$Y = 10 \times 10^{10}\ N/m^2$

$\sigma = 0.3$

$m = 0.5\ kg$

B.1.1 Calculate the Force required to stretch the wire, lateral strain and work done:

Given that the wire has to be wrapped around a wooden circular disc of Circumference $L + 3$ cm.

$$Circumference = 82 + 3 = 85\ cm = 0.85\ m$$

The circumference to be wrapped is greater than the length of the wire, the wire has to be stretched by $0.03\ m$ to be able to wrap the wooden circular disc completely.

Hence the change in length is,

$$\Delta L = C - L$$

$$\Delta L = 0.85 - 0.82$$

$$\Delta L = 0.03m$$

Using the relation of Young's Modulus,

$$Y = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

Or,

$$F = \frac{Y \times \Delta L \times A}{L} - (1)$$

Here,

$$A = \pi r^2 = \frac{\pi d^2}{4}$$

$$A = \pi \times \frac{(0.03)^2}{4}$$

Substituting this into (1)

$$F = \frac{10 \times 10^{10} \times 0.03}{0.82} \times \pi \times \frac{(0.03)^2}{4}$$

$$F = 2586067.123\ N$$

Lateral Strain is given by the poisson's ratio,

$$\alpha = \frac{\Delta L}{L} = \frac{0.03}{0.82} = 0.03658536585$$

$$\beta = \sigma \times \alpha = 0.3 \times 0.03658536585$$

$$\beta = 0.01097560976$$

Work done in stretching the wire is given by,

$$W = \frac{1}{2} \times Y \times (Strain)^2 = \frac{1}{2Y} \times (Stress)^2$$

$$W = \frac{1}{2} \times stress \times strain$$

$$W = \frac{1}{2} \times \frac{F}{A} \times \frac{\Delta L}{L}$$

$$W = \frac{1}{2} \times \frac{2586067.123}{\pi \times \frac{(0.03)^2}{4}} \times 0.03658536585$$

$$W = 66924449.72\, J$$

B.1.2 Time Period for torsional oscillations:

The time period of oscillations is given by,

$$T = 2\pi \sqrt{\frac{I}{C}}$$

Where,

$$I = Moment\ of\ Inertia\ of\ the\ wooden\ disc$$

$$C = Couple\ per\ unit\ twist$$

$$C = \frac{\eta \pi r^4}{2L}$$

Here

r is the radius of the wire

L is the length of the unstrained wire

$$\eta = \frac{Y}{2(1+\sigma)}$$

$$\eta = \frac{10 \times 10^{10}}{2(1+0.3)} = 3.84615 \times 10^{10} Nm^{-2}$$

$$C = \frac{\eta \times \pi r^4}{2 \times L} = \frac{3.84615 \times 10^{10} \times \pi \times \left(\frac{0.03}{2}\right)^4}{2 \times 0.82}$$

$$C = 3729.904505\ Nm\,rad^{-1}$$

1. Moment of Inertia about the diameter of the disc

$$I = \frac{MR^2}{4}$$

Where

M is the mass of the wooden cylinder

R is the radius of this cylinder

$$R = \frac{Circumference}{2\pi} = \frac{0.85}{2 \times \pi}$$

$$I = \frac{0.5 \times \left(\frac{0.85}{2\pi}\right)^2}{4} = 2.2876423 \times 10^{-3}\ kg\ m^2$$

Now,

$$T = 2\pi\sqrt{\frac{2.2876423 \times 10^{-3}}{3729.904505}}$$

$$T = 4.920679 \times 10^{-3}\ sec$$

2. Moment of Inertia about an axis passing through the centre

$$I = \frac{MR^2}{2}$$

Where

M is the mass of the wooden cylinder

R is the radius of this cylinder

$$R = \frac{Circumference}{2\pi} = \frac{0.85}{2 \times \pi}$$

$$I = \frac{0.5 \times \left(\frac{0.85}{2\pi}\right)^2}{2} = 4.575284 \times 10^{-3}\ kg\ m^2$$

Now,

$$T = 2\pi\sqrt{\frac{4.575284 \times 10^{-3}}{3729.904505}}$$

$$T = 6.958891 \times 10^{-3}\ sec$$

Question No. 3

Solution to Question No. 2 part B:

$T = X \times 100 + N = 3 \times 100 + 59 = 359\,K$

B.2.1 calculate the de Broglie wavelength, group velocity and phase velocity of the neutron. Justify whether this neutron beam can be diffracted by a crystal:

$$E_{translational,average} = \frac{3}{2}kT$$

$$E = \frac{3}{2} \times 1.38065 \times 10^{-23} \times 359 = 7.4348 \times 10^{-21} J$$

$$E = \frac{1}{2}mv^2$$

Where m is the mass of neutron

$$v = \sqrt{\frac{2 \times E}{m}} = \sqrt{\frac{2 \times\ 7.4348 \times 10^{-21}}{1.674927 \times 10^{-27}}} = 2979.557022\,ms^{-1}$$

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{1.674927 \times 10^{-27} \times 2979.557022}$$

$$\lambda = 1.3277119 \times 10^{-10} m$$

$$V_p \times V_g = c^2$$

$$V_g = v = 2979.557022\,ms^{-1}$$

$$V_p = \frac{c^2}{V_g} = \frac{(3 \times 10^8)^2}{2979.557022}$$

$$V_p = 3.020583 \times 10^{13} ms^{-1}$$

Since the Wavelength of the neutron beam is comparable to that of interatomic distance of a crustal, the neutron beam can be diffracted by the crystal.

B.2.2 calculate the wavelength of a photon which has the same energy as that of the neutron and identify the part of the electromagnetic spectrum into which it falls:

$$E = \frac{3}{2}kT$$

$$E = \frac{3}{2} \times 1.38065 \times 10^{-23} \times 359 = 7.4348 \times 10^{-21} J$$

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{7.4348 \times 10^{-21}}$$

$$\lambda = 267364.2869\ A^{0}$$

Which lies in,

IR–C (infrared) | FIR (far infrared)

B.2.3 Uncertainty in the measurement of the neutron velocity is 1%. Calculate the uncertainty in determining the position of the neutron:

Since the uncertainty in velocity is 1%

$$\Delta v = 2979.557022 \times 0.01 = 29.7955702\ ms^{-1}$$

Uncertainty in momentum is

$$\Delta p = m \times \Delta v$$

$$\Delta p = 1.674927 \times 10^{-27} \times 29.7955702 = 4.9905405 \times 10^{-26}\ kg\ ms^{-1}$$

From Heisenberg's Uncertainty Principle,

$$\Delta x \times \Delta p \geq \frac{h}{4\pi}$$

$$\Delta x \geq \frac{h}{4\pi \Delta p} = \frac{6.626 \times 10^{-34}}{4\pi \times 4.9905405 \times 10^{-26}} = 1.056559 \times 10^{-9} m$$

Solution to Question No. 3 part B:

$V = N + 5 \times X\ kV = 59 + 5 \times 3 = 74\ V$

$a = X\ nm = 3nm = 3 \times 10^{-9}m$

B.3.1 Calculate the Bragg angles for first order diffraction from (100), (110) and (111) planes:

$$\lambda = \frac{h}{\sqrt{2 \times m \times e \times V}}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 74}}$$

$$\lambda = 1.427381 \times 10^{-10}m$$

Taking $n = 1$, since it's for first order diffraction, Bragg's Law,

$$2 \times d \times \sin\theta = n \times \lambda$$

$$d_{100} = \frac{a}{\sqrt{1^2 + 0^2 + 0^2}} = 3\ nm = 3\ nm$$

$$d_{110} = \frac{a}{\sqrt{1^2 + 1^2 + 0^2}} = \frac{3}{\sqrt{2}} nm = 2.121320\ nm$$

$$d_{111} = \frac{a}{\sqrt{1^2 + 1^2 + 1^2}} = \frac{3}{\sqrt{3}}\ nm = 1.73205\ nm$$

1. (1 0 0) Plane

$$\sin\theta = \frac{n\lambda}{2d} = \frac{1 \times 1.427381 \times 10^{-10}}{2 \times 3 \times 10^{-9}}$$

$$\theta = \sin^{-1} 0.0237896 = 1.363177° = 1°21'47.44''$$

2. (1 1 0) Plane

$$\sin\theta = \frac{n\lambda}{2d} = \frac{1 \times 1.427381 \times 10^{-10}}{2 \times 2.121320 \times 10^{-9}}$$

$$\theta = \sin^{-1} 0.03364364 = 1.92800° = 1°55'40.82''$$

3. (1 1 1) Plane

$$\sin\theta = \frac{n\lambda}{2d} = \frac{1 \times 1.427381 \times 10^{-10}}{2 \times 1.73205 \times 10^{-9}}$$

$$\theta = \sin^{-1} 0.0412049 = 2.361538° = 2°21'41.54''$$

B.3.2 Calculate the density of the material, if the atomic weight is 107.5 kg/kmol:

The relation of density of material is given by,

$$\rho = \frac{Z \times M}{N_A \times a^3}$$

Where,

$\rho = density\ of\ the\ material$

$M = atomic\ mass\ of\ the\ material$

$Z = effective\ number\ of\ atoms\ per\ unit\ cell$

$a = length\ of\ the\ side\ of\ the\ cube$

$Z = 4$ for FCC

$a = 3\ nm = \ 3\ nm$

$$\rho = \frac{4 \times 107.5 \times 10^{-3}}{6.022 \times 10^{23} \times (2 \times 10^{-9})^3}$$

$$\rho = 26.44624\ kg\ m^{-3}$$

B.3.3 Specify the maximum order of diffraction that can be observed for (100) planes:

$n \propto \sin\theta$

To maximize n, $\sin\theta$ must be maximized, the maximum value of $\sin\theta$ is 1 at $\theta = \frac{\pi}{2}$

For (1 0 0) plane $d_{100} = 3nm = 3 \times 10^{-9}$

$$n = \frac{2d\sin\theta}{\lambda}$$

$$n = \frac{2 \times 3 \times 10^{-9} \times 1}{1.427381 \times 10^{-10}}$$

$$n = 42.0350 \approx 42$$

Question No. 5

Solution to Question No. 4 part B:

$m = 0.5 \times N + 10 \times X = 0.5 \times 59 + 10 \times 3 = \ 59.5\frac{kg}{kmol} = 59.5 \times 10^{-3} kg\ mol^{-1}$

$\rho = 1000 \times 3 = 3000\ kg\ m^{-3}$

$\sigma = 4 \times 10^{6}\ \Omega^{-1} m^{-1}$

$T = 300K$

B.4.1 Calculate the number of free electrons per unit volume, if each atom contributes a single valence electron:

$$n = \frac{\rho \times N_A \times Z}{m}$$

Where,

$Z = number\ of\ valence\ electrons$

$\rho = density\ of\ the\ metal\ in\ kg\ m^{-3}$

$N_A = Avagadro's\ constant = 6.022 \times 10^{23}\ mol^{-1}$

$m = atomic\ weight\ in\ kg\ mol^{-1}$

$$n = \frac{3000 \times 6.022 \times 10^{23} \times 1}{59.5 \times 10^{-3}}$$

$$n = 3.0363 \times 10^{28}$$

B.4.2 Determine the mean free path of the electrons:

To calculate the mean free path of the electron the relaxation time is to be calculated, which is given by,

$$\tau = \frac{\sigma m}{ne^2}$$

$$\tau = \frac{4 \times 10^{6} \times 9.1 \times 10^{-31}}{3.0363 \times 10^{28} \times (1.6 \times 10^{-19})^2}$$

$$\tau = 4.68292 \times 10^{-15} sec$$

The thermal velocity v_{th} is given by,

$$v_{th} = \sqrt{\frac{3kT}{m}}$$

$$v_{th} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 300}{9.1 \times 10^{-31}}} = 116826.1599\ ms^{-1}$$

Now,

$$Mean\ Free\ Path = \ v_{th} \times \tau$$

Where

v_{th} *is thermal velocity at temperature T*

τ *is the relaxation time*

$$Mean\ Free\ Path = \ 116826.1599 \times 4.68292 \times 10^{-15} = 5.470875 \times 10^{-10} m$$

B.4.3 Calculate the magnitude of applied electric field to produce a drift velocity of $\mathbf{1 \times 10^{-3} ms^{-1}}$:

$$V_d = \frac{e \times E \times \tau}{m}$$

$$E = \frac{V_d \times m}{e \times \tau}$$

$$E = \frac{(1 \times 10^{-3} \times 9.1 \times 10^{-31})}{1.6 * 10^{-19} \times 4.68292 \times 10^{-15}}$$

$$E = 1.21452\ Vm^{-1}$$

1. Photonic Crystal Fibers, Advances in Fiber Optics, Elliott L. VonWeller, 2005.
2. UMEA University, Department of Physics, Advanced Materials, Photonic Bandgap Fibers, Daba Dieudonne Diba.
3. Photonic Crystal Fibers, Peter Jakopic, May 2008