ISBN: 978-93-94570-41-2

7. Electric, Photonic and Magnetic Materials

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Abstract:

Modern life has been profoundly altered by electronic and photonic materials. Without them, it would not be possible to use computers, telecommunications networks, compact disc players, video cameras, or any of the other devices to which we have grown used. The basic building blocks of nanobioelectronic for analyzing and modifying electrical impulses in the body are electrode materials with a small footprint. Bulk crystal formation, organic semiconductors, the development of thin films and nanostructures, flexible electronics, and bioelectronic interfaces are all current research topics. Due to their expanding use in the microelectronic, magnetic, and opto-electronic devices that enable goods like computers, hard drives, mobile phones, and other products, these materials are of utmost significance to contemporary society. For example, organic semiconductors are used in flexible electronics and opto-electronic devices, complex oxide materials are used in the development of new magnetoelectronic devices, and magnetic materials are used in spintronic devices. CEMS faculty and students are conducting cutting-edge research on all of these materials. We will cover electric, photonic, and magnetic materials in this essay.

Keywords:

Magnetic, Electronic, Photonic, Materials, Bioelectronic, Microelectronic, Solar Cells, Opto-Electronic Devices, LED Bulbs, Computers, Sensors, Solar Energy.

7.1 Introduction:

Electronic materials are a particular class of materials that are frequently employed as fundamental components in a wide range of device applications. These components can be found in common electronic devices such tablets, GPS units, LED bulbs, mobile phones, computers, laptops, TVs, and monitors as well as LEDs, memory, and displays. To meet the technological challenges involved with the creation of these gadgets, it is necessary to continuously work to develop state-of-the-art materials that can accommodate changing dimensions and levels of functionality.

These materials offer a wide range of possible uses, including waste heat recovery, solid-state lighting, chemical and medical sensors, solar energy, and computation. Faculty from MSE who specialize in these fields usually work with campuses' various departments' institutes. Our department's ongoing research initiatives include: [1]

- For the conversion of waste heat, high performance thermoelectric
- Metal-organic chemical vapor deposition with molecular beam epitaxy to create epitaxial heterostructures
- Ultraviolet nanowire LEDs
- Laminates of superconducting metal and oxide for energy transmission and storage
- Ceramics that are magnetic and dielectric for use in communications
- Emergent phenomena at interfaces include piezoelectricity, superconductivity, and ferromagnetism.
- Electronics based on spin and magneto-electric materials
- semiconductors with an ultra-wide band gap for high-power and high-frequency applications
- Thermo-magnetic effects and the Spin-See beck effect in solids

Electronics Materials: Electronic devices including transistors, diodes, and integrated circuits (ICs), which make up the core of contemporary electronics, are made of electronics materials. These substances frequently possess qualities including strong electrical conductivity, semiconductivity, and thermal stability. [2]

Photonics Materials: The study and manipulation of light for uses like optical communication, imaging, and sensing are all part of the field of photonics, which makes use of photonics materials. High optical transparency, little optical loss, and the capacity to bend, diffract, and guide light are just a few of the characteristics that distinguish photonics materials. Nonlinear optical materials, photonic crystals, and optical fibers are a few examples of photonics materials. Photons are produced and used in photonics in a controlled setting. Photonic applications use the visible and infrared bands of the electromagnetic spectrum as examples of the radiant energy that photons generate.

Magnetic Materials: Technologies that rely on magnetic qualities, such as data storage, motors, and sensors, require magnetic materials. These materials have distinctive magnetic behaviors due to their ferromagnetic, paramagnetic, or diamagnetic features, which enable them to interact with magnetic fields.

Electronically, electro-optically, and opto-electronically active polymers are rapidly being studied in terms of their physical and chemical properties for scientific research, technological advancement, and commercialization.

There is an increasing need for effective and transparent communication among the communities of chemistry, polymer physics, and materials because of the quick development and growing number of applications of polymers as active functional materials in the construction of electronic and optoelectronic devices, such as diodes, light-emitting diodes, switches, photovoltaic cells, analytical sensors, batteries, optical fibers, etc. [3]

7.2 Magnetic Materials and Classifications:

Five types of materials are known to make up the majority of permanent magnets in use today: ferrite, alnico, flexible rubber, and rare earth magnets like cobalt and neodymium. Surprisingly, each of these displays traits that are wildly distinct from one another. It has been established that the design of magnetic components is an essential component of the design of power electronic systems. Understanding the specifics of the magnetic materials and pertinent technology is crucial for realizing the designs of magnetic components like inductors and transformers. Due to variations in atomic structure, a material's response to being placed in a magnetic field varies greatly. [4]

In plain language, the quantity of unpaired electrons in each atom determines the magnetic behavior. Most materials can be categorized as ferromagnetic, diamagnetic, or paramagnetic based on the unpaired electrons that aid in producing a net magnetic field in that material. Figure 7.1 displays a straightforward depiction of the same.

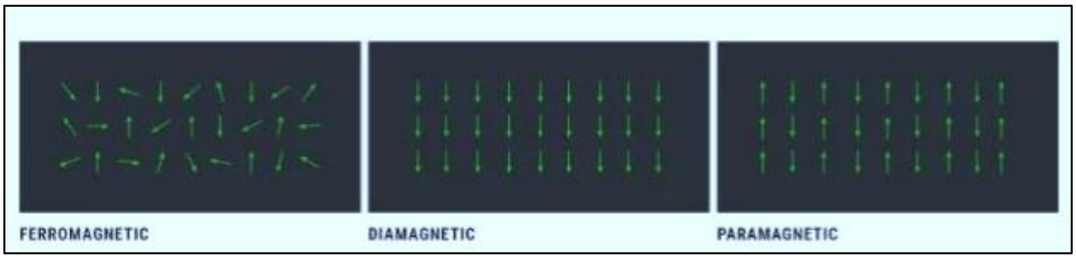

Figure 7.1: Classification of Magnetic Materials

Iron, cobalt, and nickel are examples of ferromagnetic materials, which produce a small net magnetic field as a result of having a few unpaired electrons in their atoms.

Diamagnetic materials, unlike the majority of the elements in the periodic table, are known to repel any magnetic field that is applied from the outside.

They also do not produce their own magnetic field. Materials that are paramagnetic have relatively little susceptibility to the magnetic field.

The majority of elements belong into this group because, while having a weak magnetic field attraction, they are typically considered to be non-magnetic in nature. [5]

A. Magnetic Materials:

The Englishman William Gilbert (1540–1603), who wrote the influential book On the Magnet in 1600, conducted the first genuinely scientific investigation into magnetism.

Using iron magnets and lodestones in his experiments, he was able to draw a precise picture of the Earth's magnetic field and dispel numerous myths that had obscured the issue.

After Gilbert, no fundamental discoveries were made for more than a century and a half, but there were many useful advancements achieved in the production of magnets.

Compound steel magnets, which were created in the seventeenth century and were formed of numerous magnetic steel strips joined together, were able to lift 28 times as much iron as they weighed. reversible and irreversible processes of magnetization, magnetic domains and domain barriers, magnetic anisotropy, and magnetostatics; magnetic recording, hard and soft magnetic materials; magnetism in amorphous and nanocrystalline materials; thin film magnetic characteristics, Amorphous and nanocrystalline magnetic materials, as well as magneto resistive materials, are nanoparticles; Ferromagnetic polymers, magnetic polymers containing iron, nickel, cobalt, ruthenium, or osmium, and magnetic polymers with conductivity are all examples of magnetically active polymers. [6]

7.3 Types of Magnetism:

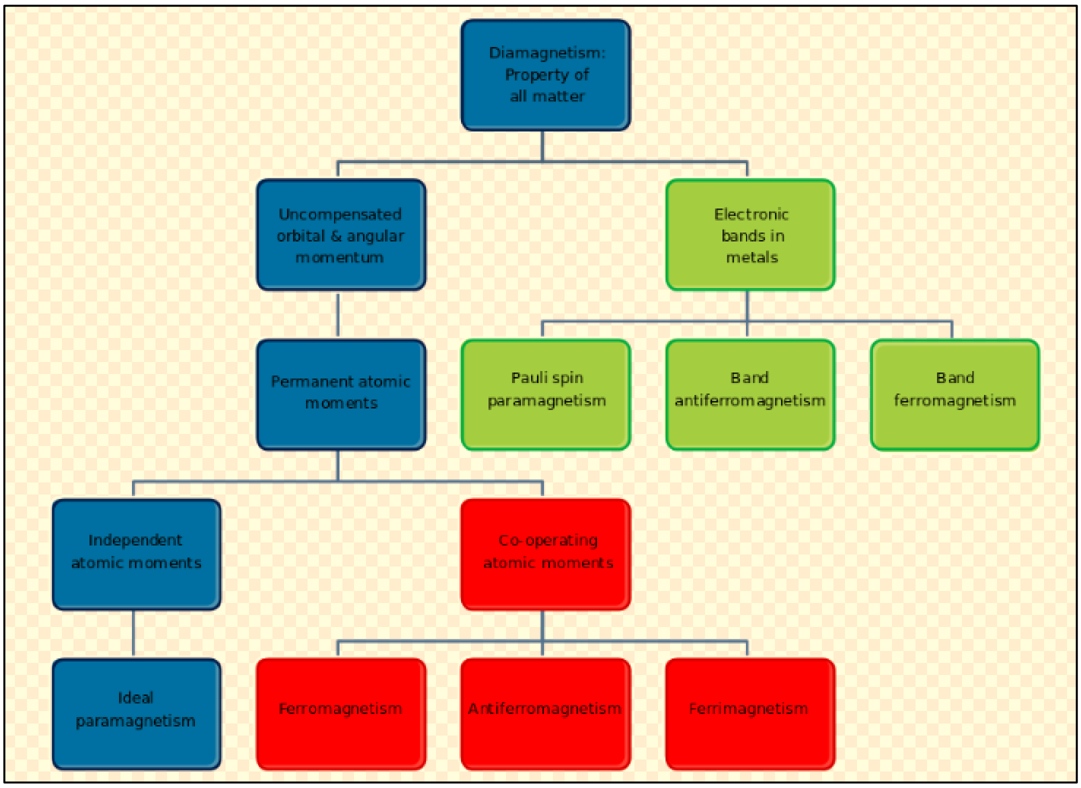

Figure 7.2: Hierarchy of types of magnetism

7.3.1 Electromagnet:

An electromagnet is a type of magnet where an electric current creates the magnetic field. When the current is cut off, the magnetic field vanishes. The magnetic field is often produced by a large number of wire turns that are positioned closely together.

In order to create a stronger magnet, the turns of the wire are frequently twisted around a magnetic core made of a ferromagnetic or ferrimagnetic material, such as iron. [7]

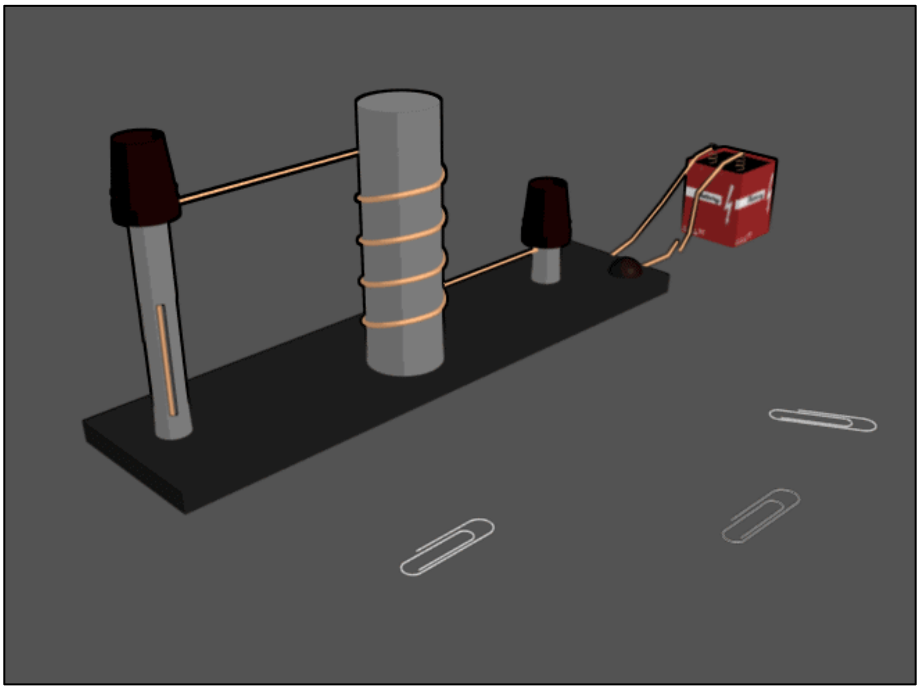

Figure 7.3: When current is added to an electromagnet, a magnetic field is created that attracts paper clips. When the magnetic field and current are turned off, the electromagnet loses them.

An electromagnet's key benefit over a permanent magnet is the ability to swiftly alter the magnetic field by adjusting the amount of electric current flowing through the winding.

An electromagnet, in contrast to a permanent magnet, needs a constant flow of current to sustain the magnetic field. [8]

Table 7.1: Typical soft magnetic materials of many types' key performance indicators. (Note: The data in the table should only be used as a general guide because the magnetic characteristics of soft magnetic materials are particularly sensitive to the production process. Please check with the sales agent for the numbers that are more specific and useful.) [9]

	Composition (wt%)	Max. relative permeability μ_{MAX}	Coercive field Hc (A/m)	Saturation polarization J_S (T)	Curie temperature T_C (°C)	Saturation magnetostriction λ_S (ppm)	Electrical resistivity ρ (μΩ*cm)
Iron/low carbon steel	$Fe_{\sim 100}$	$1\text{-}10 \times 10^3$	10-100	2.16	770	5	10
NO Fe-Si	$Fe_{bal}Si_{1\text{-}4}$	$3\text{-}10 \times 10^3$	30-80	1.96-2.12	735-765	10	25-50
GO Fe-Si	$Fe_{97}Si_3$	$15\text{-}80 \times 10^3$	4-15	2.02	750	1-3	45
Fe-(6.5 wt%)Si	$Fe_{93.5}Si_{6.5}$	$5\text{-}30 \times 10^3$	10-40	1.8	690	0.5	80
Permalloy	$Fe_{17}Ni_{79}Mo_4$	500×10^3	4	0.87	460	1	55
Permendur	$Fe_{49}Co_{49}V_2$	7×10^3	30-100	2.35	930	60	40
Sintered ferrites	$(Mn, Zn)Fe_2O_4$	$10^3\text{-}10^4$	5-20	0.4-0.55	130-280	-2	$0.1\text{-}6 \times 10^8$
	$(Ni, Zn)Fe_2O_4$	$10^2\text{-}10^3$	20-200	0.2-0.35	110—400	-20	$> 10^{13}$
Sendust	$Fe_{85}Si_{9.5}Al_{5.5}$	$50\text{-}110 \times 10^3$	1-10	1.70	670	1	110
Amorphous alloys	$Fe_{bal}Si_{7.6}B_2$	100×10^3	2-5	1.56	415	37	120
Nanocrystalline alloys	$Fe_{bal}Cu_{1.3}Nb_{5.7}Si_{7.7}B_2$	500×10^3	0.5-1	1.24	600	2	120

7.3.2 Photonic Material:

Ray optics, electromagnetic optics, and guided wave optics; the optical characteristics of semiconductors, dielectrics, and polymers; LEDs, lasers, photodetectors, modulators, optical filters, and photonic crystals; Physics of light-matter interactions; Radiation-sensitive resisters and photoactive polymers optical characteristics of polymers with s- and p-conjugates, process of relaxation in organic polymer systems, polymer light emission, Photorefractive polymers, polymers with strong two-photon activity, and device design principles for LEDs, lasers, and photo-detectors are examples of polymeric materials with nonlinear optical features.

A photon (light) is created, detected, and then modified through transmission, emission, signal processing, modulation, switching, amplification, and sensing.

This is the basic concept of the science of photonics. The proper application of light as a tool for human benefit is the most significant aspect of photonics.

A wide range of technologies, including optical fibers, lasers, detectors, quantum electronics, fibers, and materials, make up photonics.

The term "photonics" was first used to refer to a branch of study that focuses on using light to carry out operations that are typically associated with the traditional subject of electronics, such as communication, data processing, and so forth.

Following the discovery of lasers in 1960, research in the subject of photonics started. Other advancements followed, such as the development of information-transmitting optical fibers, the introduction of the laser diode in the 1970s, and erbium fiber amplifiers. [10]

An application of producing, detecting, and manipulating light in the form of photons through emission, transmission, modulation, signal processing, switching, amplification, and sensing is known as photonics.

Quantum electronics and photonics are closely related, with quantum electronics focusing on the theoretical side and photonics on its industrial applications.

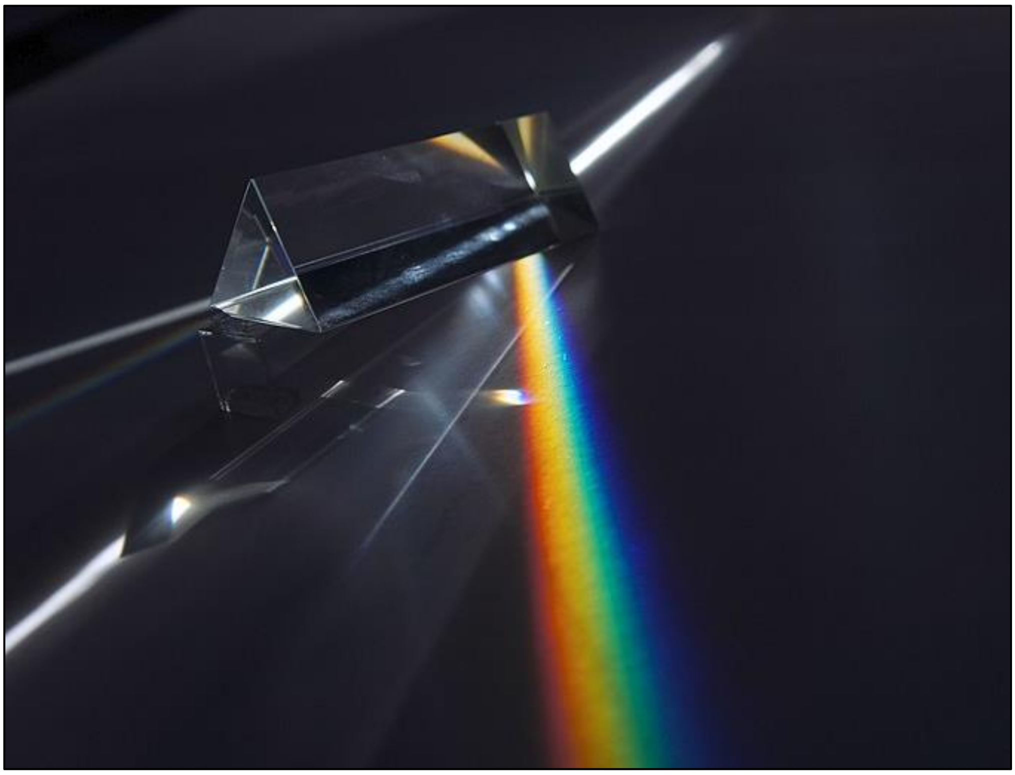

Figure 7.4: Dispersion of Light (Photons) by a Prism

7.3.3 Electric Material:

Conductivity applications, electronic applications (EMI shielding, frequency-selective surfaces, satellite communication lines), and electroactive applications Diodes, transistors, photodetectors, solar cells (photovoltaics), displays, lasers, optical fibers and optical communications, photonic devices, magnetic data storage, and spintronics are just a few examples of the applications.

Polymer applications for electroluminescence, light emitting diodes, optical switches, and optical fiber applications are also included. [11]

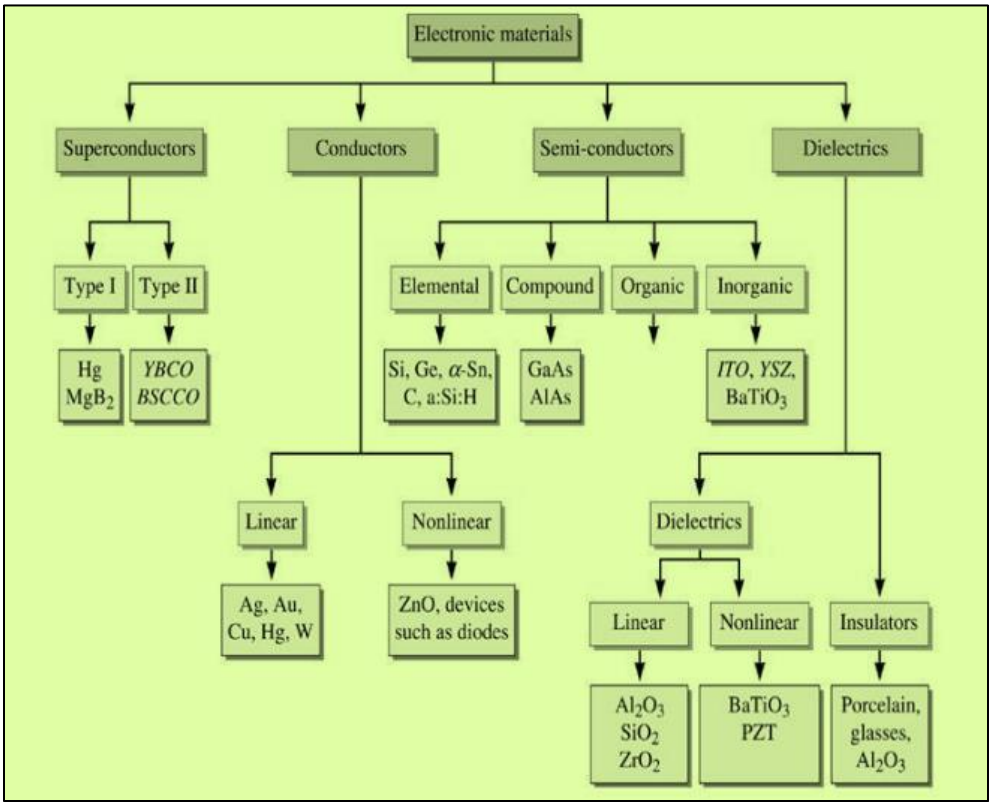

Figure 7.5: Classification of technologically useful electronic material

Engineering materials are significant in daily life due to their flexible structural characteristics. They do play a significant role in addition to these characteristics because of their physical characteristics. Electrical, thermal, magnetic, and optical qualities are some of a material's main physical characteristics. Engineering materials' electrical characteristics and uses in electrical applications are both varied. Electrical characteristics are used to categorize materials into conductors, semiconductors, insulators, and superconductors.

This chapter's main goal is to investigate materials' electrical properties, or, more specifically, how they react to an applied electric field. We start with the concept of electrical conduction, including the terms used to describe it, the mechanism by which electrons conduct, and how the electron energy band structure of a material affects its conductivity. [12]

In addition to insulators and semiconductors, these concepts also apply to metals. The features of semiconductors are given special consideration, followed by semiconducting devices. The dielectric properties of insulating materials are also covered. In terms of electronics, the materials can be divided into Insulators, Semiconductors, and Conductors.

- Insulators – Materials with a large prohibited gap that prevent conduction from occurring are known as insulators. Example: Rubber with wood.
- Semiconductors – These materials have a narrow forbidden energy gap, allowing for conduction to occur when an external energy source is applied. Germanium and silicon are two examples.
- Conductors − Conductors are those types of materials in which the forbidden energy gap vanishes as the valence band and conduction band approach and overlap. Aluminum and copper, for instance.

7.4 Electronic Materials and Devices:

The materials employed as key components in many different device applications are often of the electronic variety. These components may include memory, displays, and LEDs, and they are commonly found in everyday electronic devices including cell phones, computers, laptops, tablets, GPS units, LED lightbulbs, TVs, and monitors. To meet the technological challenges involved with the creation of these gadgets, it is necessary to continuously work to develop state-of-the-art materials that can accommodate changing dimensions and levels of functionality.

For instance, the discovery of technologies like liquid crystals, organic semiconductors, and electroluminescent materials made it possible to switch from CRT-based displays to LCD and eventually LED-based displays.

The response of electrons and other charged particles to external stimuli, such as electrical potential difference and its variation, incident electromagnetic radiation, magnetic field, heat, mechanical forces, etc., determines a material's electronic properties.

The internal structure of a material at various length scales, chemical composition, intrinsic and extrinsic flaws, as well as the dimensionality (zero, one, two, or three dimensional) of the material are all significantly connected with how the material responds to stimulation from the outside.

Table 7.2: Typical Magnetic Materials Used in Electrical Machine Cores:

Sample	Material Type	Material Composition	Sheet Thickness (mm)	Flux Density at 0.8 kA/m (T)	Flux Density at 2.5 kA/m (T)	Resistivity (μΩcm)	Material Density (g/cm^3)
A	CoFe	49% cobalt, 49% iron, 2% V	0.2–0.5	2.1	2.23	40	8.12
B	NiFe	40% nickel, 60% iron	0.1–0.5	1.44	1.48	60	8.2
C	High-silicon-content SiFe	6.5% silicon, iron balanced	0.1–0.2	1.29	1.4	82	7.49
D	Thin nonoriented SiFe	3% silicon, 0.4% aluminum, iron balanced	0.1–0.3	1.15	1.63	52	7.65
E	Nonoriented SiFe	1–3% silicon, iron balanced	0.35–1	—	1.64	20–60	7.6–7.8
F	Amorphous iron	20% (silicon and boron), 80% iron	0.025	1.55	—	130	7.18
G	SMC	<1% lubrication, iron balanced	Solid material	0.71	1.22	20,000	7.57

Signals are encoded using current or voltage in electronics, which is dependent on the motion of electrons.

The speed at which electrons may flow limits the frequency at which electrical circuits can operate. This speed is influenced by inductive and capacitive effects as well as resistive losses related to electron propagation in materials.

Because of the intense interaction between electrons, which is mediated by their electric fields, electronic systems are capable of powerful nonlinear behaviors, such as switching and state transitions.

Fundamentally, electrons can be contained in stationary states in constrained areas of space because they have mass, which is crucial for memory. Electron propagation across wires, resistance, capacitance, inductance, and non-linear behavior as exemplified by transistors are the characteristics of electronic circuits (Figure 7.6). [13]

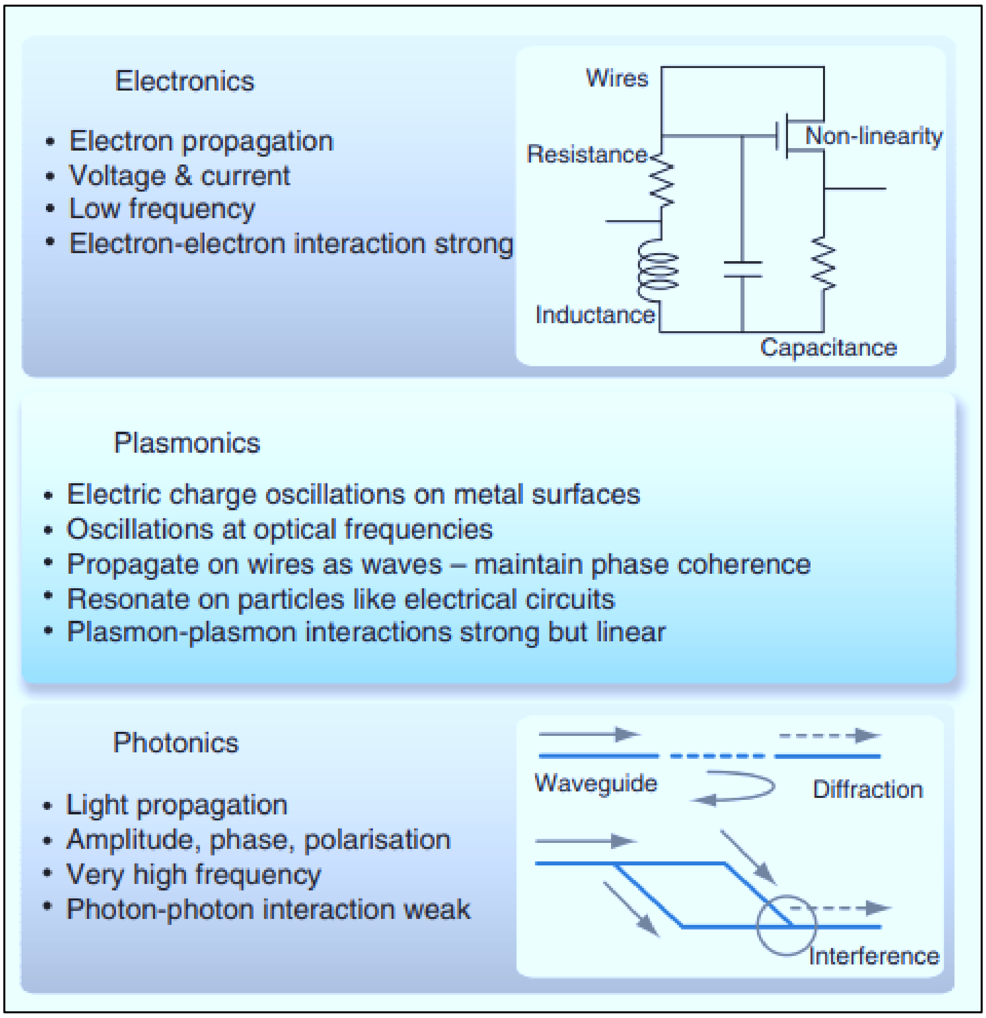

Figure 7.6: shows an evaluation of electronic and photonic circuits. The plasmonic field is situated between [14]

7.5 Conclusion:

The development of new materials with improved properties, improved performance, and novel functionalities for a variety of applications in industries like telecommunications, computing, energy, and healthcare continues to be a focus of research in these fields, pushing the boundaries of materials science. Joining this material science congress would be beneficial for meeting international scientists on one platform. The investments in materials research that are most likely to pay off are fundamental studies to deepen our understanding of current materials, the creation of new materials with extraordinary properties, processing of materials, packaging, and thermal management, theory and modeling, and materials for revolutionary technologies.

7.6 References:

1. S.O. Kasap, Optoelectronics and Photonics: Principles and Practices, Pearson Education, 2009
2. J. L. Bredas, R. Silbey, Conjugated Polymers, Kluwer, Dordrecht, 1991.
3. M. Bikales, Overberger, Menges, Encyclopaedia of Polymer Science and Engineering, 2nd ed., Vol.5, John Wiley & Sons, 1986.
4. C.P. Wong, Polymers for Electronic and Photonic Applications, Academic Press, 1993.
5. Boozer, Allen H. (2006-04-01). "Perturbation to the magnetic field strength". Physics of Plasmas. 13 (4): 044501.
6. Milton mentions some inconclusive events (p. 60) and still concludes that "no evidence at all of magnetic monopoles has survived" (p.3). Milton, Kimball A. (June 2006). "Theoretical and experimental status of magnetic monopoles". Reports on Progress in Physics. 69 (6): 1637–1711.
7. Alù A, Engheta N. Optical nano transmission lines: synthesis of planar left-handed metamaterials in the infrared and visible. J opt Soc Am B 2006; 23:571–83.
8. Nunes F, Weiner J. Equivalent circuits and anaplasmosis. IEEE Trans Nanotechnology 2009; 8:298–302.
9. Boltas Seva A, Atwater HA. Low-loss plasmonic metamaterials. Science 2011; 331:290–1.

10. West P, Ishii S, Naik G, Emani N, Shalev V, Boltas Seva A. Searching for better plasmonic materials. Laser Photonics Rev 2010; 4:795–808.
11. IPC Association Connecting Electronic Industries, "Test Manual," Northbrook, 2004.
12. Buehler Summit, The Science Behind Materials Preparation. A guide to Materials Preparation and Analysis, Buehler, 2004.
13. Pacifici D, Lezen H, Atwater H. All-optical modulation by plasmonic excitation of case quantum dots. Nat Photon 2007; 1:402–6
14. Zhang W, Jiang Y, Zhu Y, Wang F, Rao Y. All-optical bistable logic control based on coupled tam plasmons. opt Lett 2013; 38:4092–5.