ELECTRONIC MATERIAL REQUIREMENTS

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The science of electronics is literally exploding; it has risen from nothing to the fiftieth largest industry in 30 years, and from fiftieth to fifth in 20 years and it will continue to grow. This growth was made possible by the development of materials which had specific electronic properties.

Before I look into the future I would like to borrow from the past. We owe our present technical position to a few imaginative and curious scientists whose laboratories were ill equipped by today's standards. But they had a consuming desire to experiment with certain ideas, and translate the results of their work to formulas or to postulate new concepts. These early scientists were not as much concerned with material as they were with phenomena. In other words, they used available materials and many of these were those provided by nature.

This state of affairs continued until about 1906 when Dr. Lee DeForest invented the Audion Tube. This was hailed as a major contribution to the then new art of radio; note I said art, not science, for in those days it was more of a cut and try proposition than the application of scientific principles. The proponents of the tube said it could act as a generator, as a modulator to impress a coherent signal on the carrier, and as an amplifier that could amplify very weak signals to the desired intensity, a marvelous improvement over the spark gap. The Audion could even replace galena, nature's unreliable material, as a detector. But all was not well, for the tube used existing materials which were contaminated and the container was filled with gas, which created emission problems. The deficiencies existing in the materials sparked the first research for improving electronic materials, and investigations disclosed that materials used in tubes must be very pure and free from contaminates, also that gas was not a suitable material for filling a tube. The early attempts at evacuating the tube envelope were not too fruitful due primarily to unsuitable materials. By 1909 the majority of the material problems were mitigated and for the first time the Audion Tube was a manufacturable item and its performance could be predicted.

This was not the end of tube troubles; for the metallic and insulating materials used within the tube were adaptations of commercial items, and the contaminates contained therein soon destroyed the performances of the tube. Research on tube materials soon softened this problem. So by 1916 we had by today's standards a simple hard vacuum tube. For the most part electronic parts, such as the resistors, capacitors, tubes, and transistors, procurable today are very good indeed for the purpose intended, which is not for modern military systems. Some items really appear to have no wear-out features so should have infinite life - except for the intangible unpredictable failure characteristics caused during the manufacture of the part, by its material constituents or by its eventual application into circuits. Since this symposium deals with materials, one would suppose that he could omit the manufacturing and application aspects - but in fact, he really cannot forget them. In some cases these two aspects may well determine the reliability or life of the item under discussion.

In all cases an electronic material must be as suitable to withstand the mechanical stresses of handling and processing during the manufacture of an item as it must be for the eventual electrical stresses when it is a part of an electronic system. For example, the dielectric used in a particular type capacitor must be rugged enough to permit being wound from a large bulk spool, sliced to specific widths and wound on smaller spools, and then wound into a particular capacitor along with thin layers of metal foil. It must not pick up contaminates, crack, splinter, or pull thin in spots. When completely fabricated the dielectric must have the same qualities throughout from end to end. The metal foil interspersed between the layers of the dielectric must likewise be uniform in quality and characteristics from end to end in the finished product. If the winding of these two materials has not changed their characteristics, then one could say they were suitable for processing into the finished product.

If this finished capacitor has been made for use in essentially direct current circuits but is used in a place where high frequency currents also exist, the capacitor will heat from dielectric hysteresis losses, which in turn degrades its dielectric properties, which still further increases the losses, until the item eventually fails. Thus the application must be considered in the material make-up of an electronic part, and conversely the user must take care not to use a part for an unintended purpose.

Now, getting back to the material itself, in this case the basic dielectric material must be capable of being made into tough, durable sheets having a uniform thickness and uniform constituency throughout. It must not fray or tear when cut and must be so smooth that no air is trapped when wound with metallic foil. It must withstand a wide temperature range with a minimum change in its physical and electrical characteristics. It is only when these "musts" are met that reliability has a chance of being achieved in the final product.

The advancement of the technology of radio to about 1949 was a repetition of the experiences with the tube, that is, use conventional materials, find their weaknesses, establish a fix, cut and try, and keep on cutting and trying.

During this time many theories were expounded then lay dormant. Maybe a lot of them, for lack of a tailored material to fit the special requirement. One of these theories was concerned with the mobility and control of electrons in solid state devices. The translation of this theory to hardware required a close examination of what functions electronics must perform. From this an entirely new man made device was developed, the transistor. The transistor used a material that was expressly created to perform a specific function.

The success of this work, in overcoming many of the inefficiencies and unreliability of conventional devices opened up a new technology, the science of creating materials for specific electronic functions, or a better control by man of nature's processes to meet the challenge of more versatile electronics. We must have what Frank Oliver calls leap frogging research; we must reach for scientists capable of looking ahead to the goals of large ultimate consequences rather than just unimaginative hole plugging.

It was only after we started using extremely high purity monocrystalline materials that we could really begin to know and understand and predict the behavior of devices made therefrom. Until that time we had been using aggregate type materials made up of a mixture of many materials - mainly physical mixtures of simple to very complex chemical compounds - both organic and inorganic. "Cook Book" technology, cut and try techniques, and the like were employed - not only in concocting the initial material itself but a similar philosophy was employed in its processing into electronic items in the eventual circuitry. The philosophies of "let's try it" and "see if it works" are still used when we should be tailoring our efforts about well known chemical and physical facts. It's high time we learned to get away from cliches as "the operation was a huge success - but the patient expired."

The method of testing thousands of items for thousands of hours is far too costly, takes too much time and trusts too much to luck - that is, luck in that the materials and processes are stablized and not subject to change. Such reliability testing, used on all items that must be extremely reliable, is too great a burden for the country's economy to bear. The real solution is to make our materials so stable, so homogeneous, so consistent, that reliability is a natural with standard automated processing and sound application.

I have attempted to illustrate the idea that further advances in electronics will be limited by the advances made in electronic materials, and this points up various areas which must be investigated if we want our material technology to lead our operational requirements. I would like to discuss a few of these at this time. My remarks will be limited to the broad and long range concepts, specific hardware will be covered by speakers who will follow me.

Reliability of Electronic Materials

One of the greatest problems that confronts us today is the reliability of our electronic equipment. It will not be possible to perform the contemplated military or space functions of the future with electronic equipment having mean time to failure of 3-5-10-50-100 or 1,000 hours. We must think of mean time to failure in the order of 10,000 - 50,000 and 100,000 hours. This will require that certain materials used in parts or subsystems must have failure rates of less than .0001 percent per 1,000 hours operations. Note I stated materials not parts, for behind each part failure lies a material failure, also future electronic systems will in all probability be designed with functional blocks, wherein the electronic parts as we know them today will lose their separate identity and the part phenomena will be grown as part of a solid block. Research is needed to acquire an understanding of the molecular behavior of materials under static or dynamic conditions, and how this behavior contributes to failure. I would like to quote from the 1961 Book published by DOD titled "Important Areas of Electronic Research."

> "Reliability of components must be based on a deep understanding of the materials and processes that go into their fabrication. Much good work is being done to achieve this understanding, and on its success the reliability of future large weapon systems depends. I therefore rate the basic work toward achieving this understanding as the most important contribution toward reliability."

I have been subscribing to this premise for the past 15 years and it is good to see others striving for the same purpose -- that is, a better understanding of the properties of matter, how to control and how to use them. Just pause for a moment and visualize the tremendous electronic materials research effort implied by the simple title -- Reliability of Electronic Materials.

Solid State Research

Certain aspects of germanium and silicon materials for transistors appear to have sufficient emphasis placed on them, but we seem to be a nation of research followers rather than a nation of independent research thinkers. As result of this we find many capable researchers waiting for somebody else to spark the idea and he then will get on the bandwagon and never seems to know when to let loose and pursue something new. We need a greater percentage of our scientists to be bold new creators rather than docile followers. Let's take some of the research energy we are directing toward silicon and gernamium and direct it toward looking for new phenomena, rather than incrementally improving material or duplicating some other scientists' effort. Let us broaden our solid state research to include stability, low temperature operation, and fabrications to preselected specifications.

It would appear that one of the payoff efforts would be to forget about electronic construction as we know it today, and break down electronic functions into various phenomena such as generation, amplification, mixing, modulation, demodulations, display, and synthesize black-box electronic function from physical processes.

Laser

We found the material for the operation of the laser by chance, not design, I cannot help wondering how much further ahead we would be if our materials people would have anticipated this need and had the material knowledge waiting for the application. As it is, now that the principle has been established, we must concentrate research on suitable materials. What can we do with such a material? The ability of the laser to transfer efficiently the broad band energy into the energy of a single optical line, makes it possible to concentrate the emergent coherent light to a fine focus and to achieve effective communication, point to point transmission of power, or concentrate a tremendous amount of energy at some distant point. This is food for thought.

Radomes

The problem of material for electrically transparent housings has never been adequately solved.

Super Conduction

Basic work is needed on alloys that act as super conductors at normal temperatures without the basic materials being super conductive.

Super conductors which exhibit magnetic properties are desired.

Ceramics

Flexible ceramics with high insulating resistance in the microwave area would be a worthwhile project. Specialized materials for specific application which do not require doping are desired.

Organic Semiconductors

These open up a whole new research area.

Materials for Electron Tubes

The day of the simple glass enclosed electron tube is nearing an end. During its heyday, very clever automated machinery with fairly reasonable controls, made the glass envelopes, hermetically sealed in the various internal structures that could withstand a fairly wide temperature range, tested and packaged the final product. Semiconductor items are replacing these receiving tubes for three very potent reasons: size, overall cost and reliability. The new tubes of Air Force interest are not simple amplifying or oscillating devices. Rather they have become complete electronic subsystems needing in many cases only a power supply and an antenna. They are going to get even more complex as time goes on. Higher power and higher frequencies, bandwidth, and tunability are some of the more simple goals. Structures are metal and ceramics, both of which must be non-porous, withstand extreme temperature ranges and be rugged enough to withstand the mechanical stresses encountered in aerospace systems.

Ceramics are used to provide electrical insulation. However, good electrical insulators are also good heat insulators. High power requires that tubes handle and dissipate a great deal of heat. Therefore, the ceramics used in tubes should be a good insulator for electricity and a good conductor of heat. Ceramics generally are not such good electrical insulators at high temperatures, hence this places another requirement on the ceramic. Still another, it must not absorb microwave energy, and that is the type of tube we are mostly interested in for millimeter and submillimeter waves.

Since tubes are made of ceramic and metal and are still vacuum inside, there must be a vacuum tight seal or bonding between the metal parts and the metal to ceramic parts. Here again cut and try techniques are used. The chemistry and physics of the surface and sub-surface properties of such bonding should be thoroughly studied to determine the reactions involved and the optimum procedure to be employed to achieve vacuum seals, keeping in mind that during processing the parts may reach temperatures of over 1000°C and after completion may cycle from -65° to +750°C.

Many of these tubes require external magnetic elements to control the path of electrons flowing within the tube. Here the needs may be stated as:

a. Coercive Force - The need is for a constant or nearly constant coercive force versus temperature curve. Temperature range -65° to a minimum of 250°C. Also higher coercive forces are needed.

b. Nuclear Radiation - Most of the high coercive strength material contains cobalt. Cobalt has a long half life. Need is for material which does not retain radioactive properties after radiation exposure.

c. Periodic Focusing - The Alnico series so far have not been usable to periodic focusing of traveling wave tubes. Ferrites have been used extensively. The need is for a light weight material with Alnico's flat coercive force versus temperature characteristic and the ferrites' machinability and ability to retain magnetic field under shock and vibration.

Other Tube Problems

There are other tube problems with the possibility of solution by studies as indicated below:

a. Study of high strength metal whiskers for storage screen mesh in image tubes.

b. Study of high strength dielectric material whiskers for storage mesh in memory tubes.

c. Study of Electrets for memory tubes.

d. Study of single crystal selenium and other possible materials of high resistive property for EBIC Camera Tube.

e. Study of secondary emitting properties of materials used in Imaging and Memory Tubes.

f. Study of photo emission.

g. Study of electron bombardment induced conductivity in dielectric materials for imaging and memory tubes.

h. Study of material photo emissive in visual octave and photo conductive to the infrared octave of the electromagnetic spectrum.

i. Search for anisotropic resistive material for use in image storage tube target.

j. Search for anisotropic material as a substitute for fiber optics and as a substrate for photo sensitive - phosphor sandwich used in image amplifier tubes.

Solid State Materials

I have covered only a few items. There are many thousand more, an infinite variety of thin films in all possible variations and forms either as single or multilayer films to give electronic functions and eliminate inter-connections, which is one of the biggest problems we have in electronics. In studying the mechanical properties of materials we may discover the secret of long life. The field of materials research is as broad as your initiative. It is one field in which you cannot do research by ballyhoo. Your results must be accurate and informative and free of all gimmicking. I could point to some recent publicity releases and papers which made unwarranted claims, and questionable use of terms and distortions of scientific concepts, and state this type of ballyhoo does not add anything to the scientific literature, but does a lot of harm, by instilling a false sense of well being in top management, and colors their decisions on critical problems. I think a fitting close for this presentation would be a condensation of Mary Alice Hilton's remarks on keeping an open mind, "Most of us have become immune to miracles, we are inundated by them. There are miracle electronic devices, miracle drugs, miracle computing machines, all the other 100 miracles. To this array we would like to add just one more (Very Special) miracle, it is positively the last, for it is the miracle of all miracles. It is the miracle of the not yet discovered and the not yet invented. The miracle of the not yet known, and the not yet tried, the miracle of the not yet experienced and the not yet achieved, the miracle of all the machines we have yet to build, all these appear to have one catalyst, that makes it happen, an open mind, to find irresistibly fascinating peaks where others have trudged along a plane of monotony."