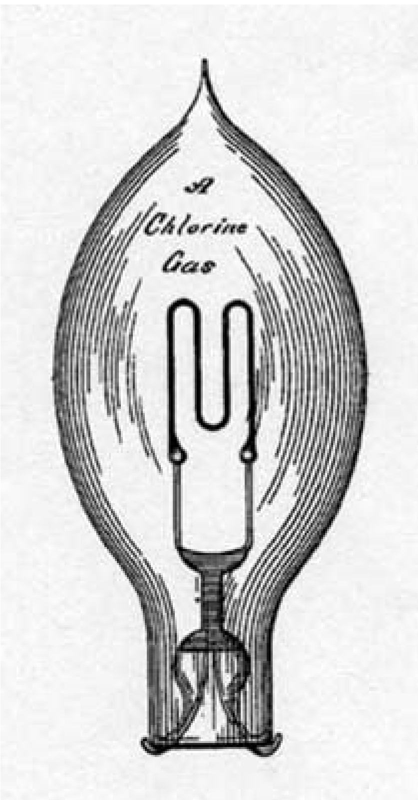
The Tungsten-Halogen Lamp

Prologue

The common light bulb of today has been around since Thomas Edison introduced it in the year 1880. It has always been the desire to eliminate, or at least reduce, the bulb blackening that appears in all lamps, and which is one cause of light reduction with time. Two attempts to alter the nature of the darkening in carbon filament lamps will be mentioned briefly. With the advent of the gas-filled lamp in 1913 blackening was reduced somewhat and the location of the discolored area was changed due to the presence of convection currents. Then, a lamp that gives 100% lumen maintenance throughout life, the tungsten-iodine, is reviewed. In addition, biographical sketches of three individuals who were key contributors in the success of the regenerative cycle lamp are presented.



The Scribner Lamp

In the year 1882, Edwin A. Scribner, assignor to the United States Electric Lighting Company, applied for, and was issued, a patent for a carbon filament incandescent lamp with a chlorine addition. The drawing of the lamp, scanned from the patent, is shown to the left. The filament design, in the shape of the letter "M", is that due to Hiram S. Maxim. The patent granted to Scribner is dated March 7, 1882 and numbered 254,780. In Scribner's words:

"When electric lamps containing a stem of carbon in a vacuum receiver are rendered incandescent it is found that the interior surface of the globe becomes clouded by a thin deposit, which disfigures the lamp and intercepts a great part of its light. I have found that under certain conditions the presence within the globe of chlorine effectually prevents this clouding, this being probably due to a chemical combination, under very high temperatures, of chlorine and carbon protoxide, resulting in the formation of a vapor or liquid rather than a solid deposit. The conditions under which this result is best attained are that the globe should contain no atmospheric air and only a very small quantity of chlorine, and in order to obtain these conditions at least approximately, the following is the method pursued.

"It is usual to attach a number of lamps to the same exhaust apparatus and to exhaust them simultaneously. To the same apparatus, and in direct communication with the lamps, a small retort capable of being filled with pure chlorine gas is also attached, and provided with a stop-cock, by which communication with the lamps may be shut off. This retort being filled with chlorine and disconnected from the lamps, the latter are exhausted of air as completely as possible, when the stop-cock is opened and the gas allowed to enter the lamps. By the diffusion of the gas the lamps become filled with an attenuated atmosphere of chlorine, and in this condition they are tested and sealed."

This writer does not know if a chlorine addition was ever used in production lamps.

The Novak Lamp

A limited use of a halogen (fluorine, chlorine, bromine or iodine) gas in the manufacture of an incandescent lamp occurred when John Waring, of the Waring Electric Company, was granted U. S. Patent No. 497,038 on May 9, 1893. The lamp, which had a small amount of bromine in it, was known as the "Novak" and was produced in 1893 and 1894. Apparently the presence of bromine did reduce the degree of discoloration and, in addition, the darkening was greenish in color instead of the usual black[1]. The basic Edison filament patent, over which so much patent litigation occurred, expired in November 1894; the Novak lamp (shown to the left) probably wasn't manufactured after that date.

The Tungsten-Halogen Lamp

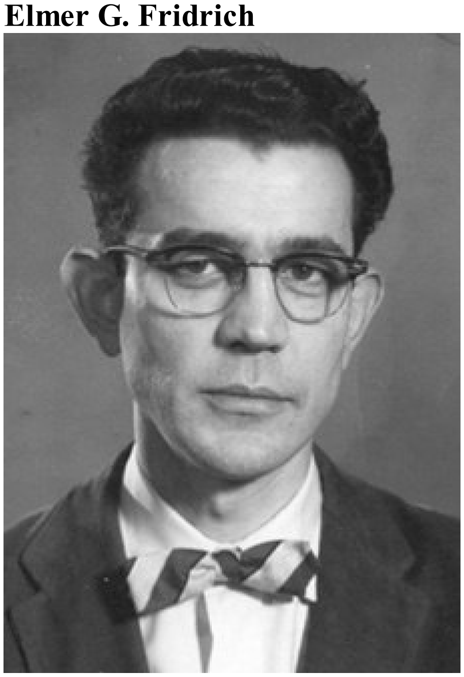
Apparently the idea of putting a halogen gas or compound into an incandescent lamp was pretty much forgotten for several decades after the appearance of the Novak lamp. The next noteworthy attempt to use a halogen occurred in the early 1950s following the formation of a small group, for the purpose of developing a heat lamp, at

the General Electric lighting headquarters (named Nela Park, in E. Cleveland, Ohio). The group was under the leadership of Alton Foote. The lamp, which was to be used for drying purposes, was to have a small diameter outer envelope of fused quartz instead of the traditional larger reflector type bulb. A marked difference between the reflector type of bulb and the quartz bulb is that the quartz can withstand much higher temperatures. During operation it is possible for the quartz to become red hot.

Linear quartz heat lamps were made in the laboratory but sometimes it was found that they would blacken. One of the workers in the group was Elmer G. Fridrich. Fridrich's assignment to that group resulted in an unforseen benefit to the lighting industry that was to be realized many months later. Elmer had read about a refining process for exotic metals in a chemistry and metallurgy magazine; the process utilized a halogen cycle. For about six months the similarity of the refining apparatus and a vertically burning quartz heat lamp continued to intrigue Elmer. One day, after the chores of the workday had been completed (that is, following the making of a certain number of heat lamps), Elmer asked Al Foote if he could pursue an idea that he had; the idea was to put some iodine in the lamp to determine its effect. Permission was granted, and Elmer then consulted with some of the older technical personnel, including Carl Kenty. It was during these consultations that Elmer learned that halogens had been tried in (carbon filament) lamps before. At least two patents had been granted, as mentioned above. As a result of these consultations it was decided to proceed with the idea to add iodine to some lamps.

One of the engineers at that time was William F. Hodge. Bill was nearing retirement and in his laboratory he had an unused vacuum system that was offered to Elmer for lamp processing. In addition to allowing Elmer to use his vacuum system, Bill supplied Elmer with tubulated clear quartz heat lamps which had tungsten supports. Another colleague, Mary Jaffe, supplied Elmer with iodine. At that time Elmer had no experience in "tipping off" lamps and so he approached another colleague and friend, Emmett H. Wiley, who did have the necessary experience in tipping off lamps from a vacuum system. The stage was now set for the first quartz tungsten filament halogen lamp to be made with a measured amount of iodine. Unlike many initial attempts at invention, this one was to be, in Elmer's own words, "A howling success." The promise of a workable lamp seemed assured. It was to be found out later, however, that short lamp life was experienced. It became clear that additional investigations were required in order to result in a product that was consistent in its performance.

Elmer G. Fridrich



Elmer G. Fridrich was born on April 11, 1920[5]. He started out on the path to become a chemical engineer. However, in his second year he decided that perhaps that wasn't the right career route for him. Instead, he took some courses in explosives and got employment as an inspector of powder and explosives. As this was during the outbreak of World War II, and the draft was in effect, Elmer entered into Ordnance at the Aberdeen Proving Ground in Maryland. His attention was directed toward neutralizing unexploded German bombs. Elmer attended a specialized Army training program at Pennsylvania State College. This led to service in the Chemical Warfare Service at Camp Sibert, Alabama. Toward the end of World War II Elmer taught machine shop as a therapy aid at Welch Convalescent Hospital.

Elmer Fridrich started his General Electric employment at the Welds Works in Cleveland as a machinist. Because his talent in developing needed apparatuses was recognized, it was recommended that he be transferred to Nela Park. At Nela Park Elmer worked under Duryea E. "Red" Elmendorf. He worked on a less expensive inside coating for incandescent lamps as well as a zinc oxide coating. After a period of time Elmer was assigned to work under Alton Foote, the team leader of the group that was to develop a quartz heat lamp.

A great advantage of developing a product by a group of people is that a wide range of talent, education and experience comes into play. When the darkening of the new quartz heat lamps was recognized as a real problem it was decided in early 1954 to bring Ed Zubler, a physical chemist, into the picture. As time went on Fridrich and Wiley played reduced roles in the project.

Fridrich and Wiley applied for a patent on March 3, 1958 and U.S. Patent No. 2,883,571 was granted on April 21, 1959. In that patent a modified lamp design also was presented by Fridrich. Later in time he proposed a lamp which he called "the Gemini". The lamp was designed to operate at one-half of line voltage; two such lamps were to be operated in series.

The photograph of Elmer Fridrich, shown above, was taken in 1959.

Listed below are 38 of Elmer's patents:

1) Nov 19, 1957 — United States — 2,813,327 —Apparatus for and method of forming and mounting supports on coiled filaments
2) Nov 19, 1957 — United States — 2,813,993 — Electric lamp or similar device
3) Apr 21, 1959 — United States — 2,883,571 — Electric incandescent lamp
4) Aug 25, 1959 — United States — 2,901,652 — Electroluminescent lamp construction
5) Sep 15, 1959 — United States — 2,904,457 — Manufacture of conductive glass paper
6) Dec 22, 1959 — United States — 2,918,594 —Variable color electroluminescent lamp
7) Jul 19, 1960 — United States — 2,945,976 — Electroluminescent lamp and manufacture thereof
8) Mar 28, 1961 — United States — 2,976,893 — Lamp making machinery
9) Mar 13, 1962 — United States — 3,025,424 — Electric lamp
10) Jul 31, 1962 — United States —3,047,052 — Apparatus for laminating an electroluminescent cell lay-up
11) Dec 4, 1962 — United States — 3,067,357 —Electric discharge lamp electrode
12) Sep 3, 1963 —United States — 3,102,443 — Mechanism for forming ribbon leads (with Paul A. Dell)
13) Apr 19, 1966 — United States — 3,247,477 — Photoconductive electrical component
14) Jul 5, 1966 — United States —3,259,777 — Metal halide vapor discharge lamp with near molten tip electrodes
15) Jul 5, 1966 — United States — 3,259,778 — Starting of high temperature electrode lamps
16) Aug 2, 1966 — United States — 3,263,852 — Method of glass bulb manufacture and glass bulb
17) Feb 21, 1967 — United States — 3,305,289 — Electric lamp manufacture
18) Apr 18, 1967 — United States — 3,315,111 — Flexible electroluminescent device and light transmissive electrically conductive electrode material therefor
19) Aug 19, 1969 — United States — 3,462,209 — Method of making vacuum type electric incandescent lamps
20) Jun 1, 1971 — United States — 3,582,704 — Manufacture of foil seals
21) Sep 26, 1972 — United States — 3,693,241 — Manufacture of foil seals
22) Aug 10, 1976 — United States — 3,974,418 — Fluorescent lamp unit with ballast resistor and cooling means therefor
23) Dec 7, 1976 — United States — 3,996,493 — Fluorescent lamp unit having ballast resistor (with John M. Davenport)
24) Oct 11, 1977 — United States — 4,053,809 — Short-arc discharge lamp with starting device (with Rolf S. Bergman)
25) Nov 13, 1979 — Canada — 1,066,248 — Fluorescent lamp unit having ballast resistor (with John M. Davenport)
26) Jun 10, 1980 — United States — 4207541 — Cooling jacket for laserflash lamps (with Arieh M. Karger)
27) Sep 30, 1980 — Canada — 1,086,813 — Short-arc discharge lamp with starting device (with Rolf S. Bergman)
28) Feb 3, 1981 — United States — 4,248,584 — Method and apparatus for dispensing salt powder as pellets in lamp making
29) Jun 23, 1981 — United States — 4275329 — Electrode with overwind for miniature metal vapor lamp
30) Apr 6, 1982 — Canada — 1121122 — Method and apparatus for dispensing salt powder as pellets in lamp making
31) Jun 21, 1983 — United States — 4,389,201 — Method of maufacturing a lamp
32) Jul 26, 1983 — Canada — 1,150,762 — Electrode with overwind for miniature metal vapor lamp
33) Apr 10, 1984 — Canada — 1,165,373 — Refractory helical overwound electrode for high pressure metal vapor lamp
34) May 15, 1984 — Canada — 1,167,513 — Method of manufacturing a lamp
35) Jul 30, 1984 — Hungary — 184,247 — Method for making lamp armature with two ends
36) Oct 15, 1985 — United States — 4,547,704 — Higher efficiency incandescent lighting units (with Walter K. Brinn, Ivan Berlec, John M. Davenport, Milan R. Vukcevich)
37) Dec 13, 1988 — Canada — 1,246,659 — Higher efficiency incandescent lighting units (with Walter K. Brinn, Ivan Berlec, John M. Davenport, Milan R. Vukcevich)
38) May 19, 1992 — Canada — 1,301,237 — Asymmetric arc chamber for a discharge lamp (with Richard P. Gilliard, Daniel M. Cap, John J. Karikas, Gilbert H. Reiling)
The following is a U. S. Patent Application —
39) Dec 25, 2003 — United States —2003/0233847 — Manufacture of elongated fused quartz member

The expertise that Elmer Fridrich has with lathes and machine equipment was of great benefit in the development of many of the above inventions. In particular, the shape of the short-arc high-intensity discharge lamp pictured in his U. S. Patent No. 4,053,809 resulted from that skill. The lamp, marketed as the "Marc 300", is used in photographic projectors.

Fridrich also was granted Design Patent No. D0248501 (with John M. Davenport), which was issued Jul 11, 1978. The design was for a fluorescent lamp with a resistor ballast, marketed as "Brightstik" (see U. S. 3,974,418).

Edward G. Zubler

Edward George Zubler was born on March 12, 1925 in Lackawanna, New York[6]. At age 18, in 1943, he entered the U.S. Army and served in the 102nd Infantry Division in the Rhineland Campaigns. During a military service career that lasted from 1943 to 1946 he attained the rank of Staff Sergeant and was awarded a Bronze Star and Purple Heart, both with the Oak Leaf Cluster. He earned a Bachelor of Science degree in Chemistry from Canisius College in Buffalo, New York in 1949. He then earned a Ph. D. degree in Physical Chemistry from the University of Notre Dame in Notre Dame, Indiana in 1953.

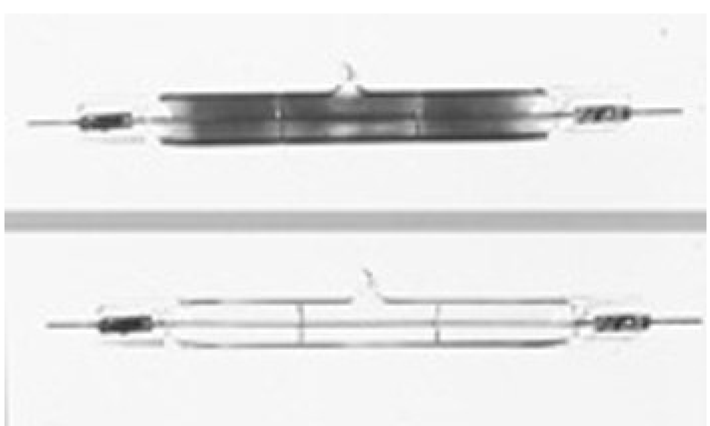
Ed Zubler's work experience with the General Electric Company began in 1953. His career extended over a period of 34 years, working in the Lighting Research Laboratory. Ed held the positions of Research Physical Chemist, Technical Leader-Halogen Lamp Chemistry, and Research Advisor-Physical Chemistry.

Zubler initiated a series of experiments to try to understand why the halogen lamp was giving short life, as reported above. The reason was found to be due to the water that was being introduced with the iodine crystals. After that discovery Zubler became a member of the team.

Zubler then began in-lamp experiments in an effort to obtain cleaner lamps. However, the net result of those efforts was just the opposite of what was desired — he produced blacker lamps. The efforts were carried out over a period of about three years with little success. At that point it was decided that if efforts to make a clean lamp were not successful, a different approach needed to be taken. The approach Zubler took was to try to make dirty lamps — and from these experiments the secrets of successful lamp making hopefully might be uncovered. At that point he began to add small quantities of oxygen to the lamps. Eureka! — clean lamps resulted, and with somewhat longer lives! However, now a new problem arose. In many cases arcing occurred, which ended lamp life prematurely. Zubler then increased the cold fill gas pressure of argon, which suppressed the arcing, and the major problems ceased to exist.

Thus, after determining that a small quantity of oxygen, as well as a higher fill pressure of argon were required, the regenerative cycle taking place within the tungsten-iodine lamp was beginning to be understood. It was found that a tungsten oxyiodide compound probably was involved in the working of the cycle. This fact could be surmised from Zubler and Mosby's patent[3], where the final filling consisted of about 600 to 1500 Torr of pure argon, about 0.3-0.5 Torr of oxygen and about 5 Torr of iodine. However, it was necessary that work be continued in order to understand the effects of envelope impurities and well as those impurities that were inadvertently added during processing. Attention also had to be given to the support wires, for example, for any role they might be playing. Zubler's studies eventually helped to establish both design and processing specifications.

A visual demonstration of the cleanup of a blackened lamp envelope is shown below. Zubler sealed lamps to his vacuum system and subjected them to a hydrogen cleanup procedure. Silicon oxides were removed by torching and the lamps were then blackened under high vacuum conditions to deposit tungsten on the lamp wall. Next, measured amounts of iodine and oxygen were added. The lamps were then sealed off. Upon operation the lamp walls would cleanup in less than one minute.



A 500-watt, 120-volt quartz iodine lamp

Listed below are lamp-related patents issued to Zubler.

> "Iodine Incandescent Lamps", U.S. 3,132,278, May 5, 1964 (with C. B. Collins)
> "Method of Manufacture Of Iodine Cycle Lamps", U.S. 3,160,454, Dec 8, 1964 (with F. A. Mosby)
> "Iodine Cycle Incandescent Lamps", U.S. 3,240,975, Mar 15, 1966 (with J. F. English)
> "Getter Composition for Electric Lamps and Similar Devices", U.S. 3,508,856, May 25, 1971
> "Getter Processes for Electric Lamps and Similar Devices", U.S. 3,679,285, Jul 25, 1972
> "Mercury Pressurized Incandescent Lamps", Canadian No. 1,280,149, Feb 12, 1991 (with E. J. Covington)

Because Zubler was so knowledgeable in the area of lamp chemistry, he was a sought-after speaker. Besides giving invited lectures in the Cleveland area, such as at Cleveland State University, Case Western Reserve University, John Carroll University and the University of Toledo, he also gave presentations at the Gordon Conference on High Temperature Chemistry, Eötvös University in Budapest, Hungary, Rensselaer Polytechnic Institute in Troy, New York, Kernsforschungsanglage-Jülich in Germany, SRI International in Menlo Park, California and at the Sandia National Laboratory in Livermore, California.

Ed Zubler married Marybelle Browning in 1950 and they have children Karen, Kurt and Rena. He retired in 1988. The photograph of Zubler was taken in the 1960s.

Note: It is with great sadness that I report that Edward G. Zubler passed away on March 20, 2004.

Frederick A. Mosby

One of the key members in the engineering group who helped establish the necessary lamp design and manufacturing equipment for the dependable operation of the iodine cycle was Fred Mosby.

Fred, born Frederick Anderson Mosby on October 24, 1924, is a native of Morgantown, West Virginia[7]. In 1943, at age nineteen, Fred joined the U.S. Navy and was sent to the Great Lakes Naval Training Station in Chicago for boot training. From there he went to Hampton Institute in Hampton, Virginia for training to become an Electrician. After completion of the Electrician course Fred was retained as an instructor. He taught for awhile and was then selected for officer's schooling.

Fred's selection for officer training enabled him to pursue studies at the University of Rochester in Rochester, New York. In 1947 he graduated, earning a Bachelor of Science degree in Mechanical Engineering and was commissioned an Ensign in the Naval Reserve. From 1948 to 1952 Fred worked as a Mechanical Design Draftsman for the Electric Storage Battery Company in Philadelphia, Pennsylvania.

In 1952 Fred Mosby joined the General Electric Company in Schenectady, New York as Electrical Designer in the Aeronautic and Ordnance System Division. In 1955 he transferred to the Incandescent Lamp Department in East Cleveland, Ohio.

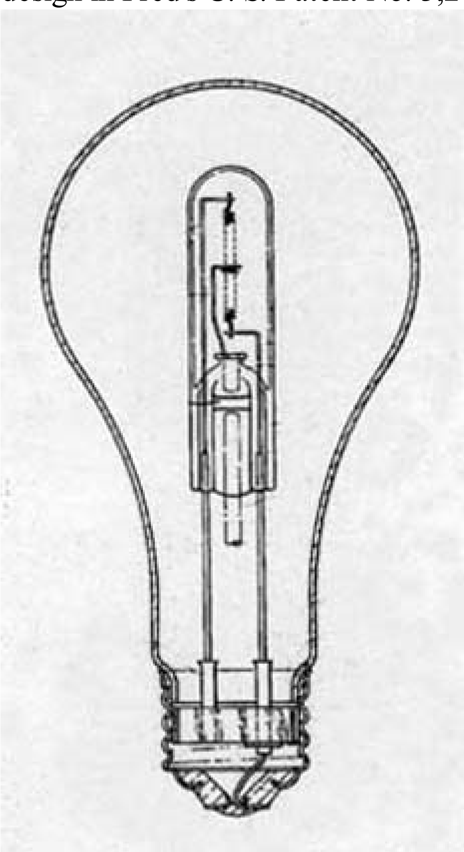
Fred married twice. His first wife, Dorothy M. Gaffin, passed away at a relatively early age. Together they had three children, two girls and one boy. Fred married a second time, to Julia I. Jones. They were blessed with two sons.

It was found during the investigation of blackening that impurities in the tungsten wire played a role. In the case of iodine lamps Mosby said[7]:

> "Because oxygen, as part of the iodine cycle, is required for it to operate, it is essential that a quantity of oxygen is available throughout life of the lamp. Tungsten impurities, if not controlled, form stable oxygen compounds that deplete oxygen thus causing the lamp to blacken. It is very difficult to control oxygen and impurities in the iodine cycle lamp."

Fred participated as a co-worker with Ed Zubler, helping to determine satisfactory iodine and oxygen levels as well as the tolerable wire impurity levels. In addition, he participated in the design and development of other halogen lamps. Developments such as these are often result of combined efforts of several individuals. Unlike the more usual effort of one individual in days past, synergism is the key to success today.

One project Fred undertook on his own was to develop a tungsten-halogen lamp that could be mounted inside an A-line bulb. Such a lamp would provide improved light output and life when compared with the common household lamp. The structure design in Fred's U. S. Patent No. 3,243,634 is shown below. Details in the patent drawing that are of no interest here were deleted from the drawing. The glass bulb was made thicker in the event the pressurized halogen lamp should ever rupture. Management made the decision not to market the lamp, apparently because of its high cost, but other manufacturers have since placed their own designs in the marketplace. Another reason for not marketing the lamp was the fact that compact fluorescent lamps, with their higher efficacies were being considered.



Of interest, of course, is the performance difference between a typical A-line, or household lamp, and the high pressure halogen lamp discussed here. Such a comparison was made in the patent description and it follows:

> "Thereby, as compared to conventional household lamps operating at, for example, about 16 lumens per watt for 750 hours in the popular 100 watt size, lamps of the halogen-cycle type may be operated at efficiencies of, for example, 20 to 25 lumens per watt for a life in excess of 2000 hours and with virtually no depreciation in light output during life."

It's of some historical interest to identify the first halogen lamps that appeared for public use. The following is the response received from Fred [7]regarding that question:

> "The first tungsten halogen lamps sold were 45-watt, 6.6-ampere lamps used to pinpoint capital cities on the world sphere at the 1960 World's Fair in New York City. Of course the number of lamps sold was rather small. However, the first halogen lamp sold in large quantities was the 28-volt, 150-watt aircraft wing tip marker. The lamp was designed and produced in the Large Lamp Department for a short time for the Miniature Lamp Department which had design and production responsibility for aircraft lighting. Stan Ackerman was the design engineer from Miniature Lamp who had responsibility for wing tip lamps. Thus, Large Lamp produced the lamp, but it was sold by the Miniature Lamp Department."

After working as a process engineer, Fred then did design work and later was Manager of Quartzline Engineering. He then became Manager of Special Incandescent Engineering and after that became a Consultant on incandescent lamps. He retired from the General Electric Company in January, 1990. The photograph of Mosby was taken in 1969.

Fred Mosby was granted eight U.S. patents that pertain to the incandescent lamp; seven of these relate to the tungsten-halogen lamp. These patents are listed below:

> "Terminal Structure for Double-Ended Lamps", U.S. 3,001,096, Sep 19, 1961
> "Method of Manufacture of Iodine Cycle Incandescent Lamps", U.S. 3,160,454, Dec 8, 1964 (with E. G. Zubler)

"Electric Lamp and Support Web", U.S. 3,242,634, Mar 29, 1966
"Electric Lamp Filament Support", U.S. 3,270,238, Aug 30, 1966
"Electric Incandescent Lamp Mount Support", U.S. 3,5002,931, Mar 24, 1970
"Incandescent Lamp and Method of Manufacture", U.S. 3,544,188, Dec 1, 1970 (with G.K. Danko)
"Cementless Base Incandescent Lamp", U.S. 4,103,201, Jul 25, 1978
"Incandescent Lamp Utilizing Cylindrical Transparent Heat Mirror", U.S. 4,916,353, Apr 10, 1990 (with G.K. Danko)

Epilogue

In a publication of the Toshiba Corporation the tungsten-halogen lamp is listed among the six most important inventions in the field of electric incandescent lamps. The list consists of 1) the first commercial carbon filament lamp, 2) the drawn tungsten filament lamp, 3) the gas-filled lamp, 4) the coiled-coil filament lamp, 5) the inside frosted lamp and, 6) the tungsten-halogen lamp.

It should be mentioned that iodine has been largely replaced by bromine in lamps manufactured today. One of the reasons for using bromine instead of iodine is the fact that when gases of greatly different molecular weights are used, such as argon (Molecular Weight, MW=39.9) and iodine (MW=126.9), thermal diffusion separation results in the heavier gas concentrating at the lower end of the lamp. This was an especially severe problem in the case of lamps having a large length-to-diameter ratio; the effect was evident when the lamp was operated just a few degrees off horizontal. The use of bromine (MW=79.9) and krypton (MW=83.8) reduced this tendency to separate significantly. The use of coiled-coils, instead of singly-coiled filaments, also minimized the problem because of the smaller length-to-diameter ratio.

A few words are in order regarding the development of a product. It is very difficult to include everyone in a review such as this and the extent of the contributions by individuals often is unknown outside the group that did the work. Exclusion of individuals, or the impact of their contributions, is not intentional in this writing. Some people contribute during the early stages of the project and others later when the project shows signs of success. In that regard it should be mentioned that Richard H. Holcomb performed work with CH_3Cl for use in a short duty cycle lamp where the lamp was turned on and off frequently. In addition, the Philips Company used CH_2BrCl in extended life lamps.

The writer, in trying to bring the essence of the development of the tungsten-iodine lamp to the reader, has concentrated on writing about three individuals. The genesis of the tungsten-iodine lamp came from the mind of Elmer Fridrich. In addition, Elmer is credited with demonstrating the potential for making a light source that could be operated without envelope blackening. Elmer then went to work on other projects while Zubler and Mosby and several other engineers and personnel took up the challenges, including processing specifications, that this new product presented. Success was eventually achieved and product introduction occurred in 1960. It was fortunate that this discovery took place in a large laboratory setting where the expertise of many persons was available. It behooved the GE organization to perform fundamental chemistry studies to determine the effects of halogen and wire purity, support wires, quartz and atmospheric contamination.

An analogous situation to the experience of the tungsten-iodine lamp work occurred with another development in incandescent lamp history. About 1913 Irving Langmuir developed the gas-filled lamp with a coiled tungsten filament. However, that development couldn't be fully utilized until Aladar Pacz developed a wire, in 1915, that neither sagged nor offset.

Acknowledgements

The writer appreciates the information and comments given by Elmer Fridrich, Fred Mosby and Ed Zubler regarding this major advance in the performance of the incandescent lamp. Each person played a major role in making available to the world a lamp that could be designed for longer life with no blackening. The photograph of Elmer Fridrich was downloaded from the Smithsonian site titled "Lighting a Revolution"; see Reference No. 13. Permission was obtained from Smithsonian personnel to use the photographic image of Fridrich. The image shown on the Smithsonian site is copyrighted by the General Electric Company.The photograph showing a clean as well as a darkened lamp was also downloaded from that site; see Reference 9. Ed Zubler and Fred Mosby kindly supplied their photographs, which are appropriate for the time of their lamp work.

References

1) John W. Howell and Henry Schroeder, History of the Incandescent Lamp, The Maqua Company, Publishers, Schenectady, New York, 1927, pg 127.
2) E. G. Zubler and F. A. Mosby, "An Iodine Incandescent Lamp with Virtually 100 Per Cent Lumen Maintenance,

Illuminating Engineering, Vol 54, pg 734, 1959.
3) Edward G. Zubler and Fred A. Mosby, "Method of Manufacture of Iodine Cycle Incandescent Lamps", U. S. Patent No. 3,160,454, Dec 8, 1964.
4) Mosby, F. A., L. J. Schupp, G. G. Steiner and E. G. Zubler, "Incandescent Bromine Cycle Lamps", *Illuminating Engineering*, Vol 62, pg 198, 1970.
5) Communications from Elmer Fridrich to the writer.
6) Communications from Ed Zubler to the writer.
7) Communications from Fred Mosby to the writer.
8) http://americanhistory.si.edu/lighting/bios/thteam.htm
9) http://americanhistory.si.edu/lighting/20thcent/invent20.htm
10) http://americanhistory.si.edu/lighting/history/patents/mosby1.htm
11) http://americanhistory.si.edu/lighting/webnotes/webnote7.htm
12) http://americanhistory.si.edu/lighting/history/patents/frid1.htm
13) http://americanhistory.si.edu/lighting/bios/frid.htm

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