FUSITE

OUTLINE

PREFACE

This booklet is intended to serve as an overview of key issues related to serving the needs of advanced battery technologies through the use of hermetic glass-to-metal seals and alternative vent designs.

Many lithium and non-lithium systems offer higher energy densities, longer shelf lives, and improved operating characteristics over traditional chemistries used in battery systems. Often these battery systems require advanced methods of sealing and venting the cells.

Many of these aspects will be briefly discussed in order to provide both a historical perspective, as well as a synopsis of current technological capabilities in delivering a superior product to the marketplace to meet a variety of demands.

We will address topics of concern with batteries of AA, A, C, D, and specially designed sizes for applications such as medical implants or industrial use. The largest market for batteries, the automotive SLI (starting, lighting, ignition) segment being served by lead-acid systems, is outside the scope of this document.

Consider this booklet as a foundation from which you can build your knowledge. Additional information on glass-to-metal sealing and advanced battery technologies can be found in the sources listed in the Suggested Reading section.

INTRODUCTION

As all markets and technologies face the realities of change, the battery marketplace is no different. New, more sophisticated battery chemistries have opened avenues of opportunity for firms with a keen focus on specific market needs; whether military, medical, industrial, or consumer-related.

Lithium battery systems are one of the newer technologies that are fundamentally changing user expectations and demands for increased battery performance characteristics. For instance: prior to the development of lithium batteries, heart pacemakers were powered by batteries that offered, typically, two years of service. The inconvenience associated with replacing these batteries is obvious. Lithium iodine systems offer a useful service life of approximately 10 years, while providing additional functions for the user. These increased capabilities are a tremendous benefit to the pacemaker patients, the true “users” of these products.

Other market segments have experienced dramatic benefits as well, recognizing significant gains from lithium battery usage in the following areas: higher cell voltage and energy densities, low self-discharge rates resulting in longer shelf life, tailored discharge curves, wide range of operating temperatures, and a variety of cathode materials useable in combination with a lithium anode.

EVOLUTION

In the 1970's, serious work began on a new series of battery chemistries which used lithium as the active material. These cells offered the potential of voltages which were more than twice as high as the Carbon Zinc and the Alkaline cells historically used. In addition, the energy capability is five to ten times higher than that of the Carbon Zinc cell.

As development work continued on a variety of lithium chemistries for battery systems, market applications have experienced solid growth as well. Specific lithium chemistries today are seeing their greatest usage in niche applications, whether medical, military, commercial, or consumer-oriented.

With its variety of advantages over previous chemistries, lithium chemistries also bring a set of concerns in these various applications. These concerns are typical in the battery industry, as many chemistries have experienced a "proving-out" period as they are adopted into new products and applications.

To-date, the majority of lithium battery systems commercially developed have been of primary or non-rechargeable design. There are some secondary, or rechargeable cells that have reached the marketplace, and expectations are for this segment to experience significant growth in the coming years.

LITHIUM BATTERY CHEMISTRIES

There are a great variety of materials used in combination with lithium to produce batteries of different chemical composition. The most commercially-adopted systems to-date include:

- Lithium-sulfur dioxide
- Lithium-maganese dioxide
- Lithium-thionyl chloride
- Lithium-polycarbon monofluoride
- Lithium-iodine
- Lithium-chromium oxide
- Lithium-molybdenum sulfide

This list is in no way exhaustive of the various combinations being explored and developed within the lithium battery marketplace, yet it provides an overview of the most highly adopted systems to-date.

There continue to be many developments in commercializing and marketing these newer battery systems. Additionally, expectations are for other systems to grow in usage, with the potential of a rechargeable lithium battery offering significant benefits over traditional nickel-cadmium cells through weight and size reduction.

Because of the wide range of systems and chemistries offered, there are various classifications of lithium batteries, including: environmental, performance requirements, and the nature of the cathode or electrolyte material. Using this last classification scheme, cathodes are typically referred to as either “solid” or “soluble”, while electrolytes are “liquid” or “solid”.

Classifying lithium cells by the nature of the cathode or electrolyte material is most significant when exploring methods of sealing the cells and considering application aspects of various designs. We will explore this in the section titled: “Why Glass-to-Metal Seals?”

MARKET SEGMENTS / APPLICATIONS

Given the wide variety of lithium battery chemistries, and the inherent strengths and weaknesses of various designs, there have emerged some more common applications of specific chemistries to address certain market segments or niches.

The market segments typically mentioned in relation to lithium battery application are: military, medical, industrial-commercial, and consumer. Each of these segments has specific needs and goals in relation to the performance of batteries used in their application. These needs and goals are met by matching the various benefits that specific chemistries offer with the design and use considerations of the market.

Following is a brief synopsis of each of these markets and some of the chemistries commonly used in their respective applications.

Military

The military market has helped push the development of higher-energy lithium systems in order to meet their wide range of needs; including applications such as: communications systems, “smart” missiles, sonobuoys, mines, torpedoes, etc. The most common lithium systems to be found in the military environment include lithium sulfur-dioxide ($LiSO_2$), and lithium thionyl-chloride ($LiSOCl_2$). Battery types include both primary and reserve cells. As in many technologies, the military has provided an avenue for manufacturers to develop new technologies and applications and “prove” these technologies through extensive field use.

Medical

The medical marketplace has experience great success through adoption of lithium battery technology. Because of the long service life of lithium systems, products such as pacemakers and heart defibrillators now offer their users significant benefits over previous battery systems used in these applications. The most popular lithium chemistry used in the medical battery market has been lithium-iodine. Additional medical products that utilize lithium batteries are under development and are expected to experience significant growth in the future. These products include: drug-delivery systems (insulin, others), neurostimulators, pumps, and portable diagnostic equipment.

MARKET SEGMENTS / APPLICATIONS CONTINUED

Industrial-Commercial

The growth of lithium battery systems is having tremendous impact on the industrial-commercial, or OEM (Original Equipment Manufacturer) market. Because of the variety of chemistries available, and the often non-interchangeable nature of lithium batteries with carbon zinc and alkaline battery systems, OEM's are looking at lithium systems with great interest and care. Products can be designed smaller, have less weight, and operate considerably longer than with previous battery chemistries. Because of this, OEM's can find a competitive edge in using lithium batteries over products that do not incorporate them.

Applications within this segment include: memory backup for personal computers, utility consumption meters, cellular telephones, and a rapidly increasing raft of new products.

A significant event that has occurred because of lithium cells' long service life, is a shift from battery manufacturers focusing solely on the consumer aftermarket to selling directly to OEM''.

Some common lithium chemistries found in the industrial-commercial segment include: lithium manganese-dioxide, lithium-polycarbon monofluoride, and lithium thionyl chloride. Because of the broad range of products, many chemistries will find significant application within well-defined market niches.

Consumer

The consumer marketplace for batteries is generally regarded as the over-the-counter retail trade. This is in contrast to the manufacturer of a consumer product supplying their goods with a battery as part of the package. The consumer marketplace for lithium batteries is evolving, with early applications in replacement batteries for cameras. Some manufacturers have developed 9-volt lithium batteries which are directly interchangeable with existing cells. The most popular chemistries reaching the consumer market are: lithium manganese-dioxide, lithium polycarbon monofluoride, and lithium thionyl chloride. As in the industrial-commercial market, many chemistries will find a significant number of applications within well-defined market niches.

GLASS-TO-METAL SEALS

Glass-to-Metal seals are a reliable method of making a long-life seal capable of operating under a wide range of conditions. These seals are capable of withstanding extremes of temperature, electrical current, pressure variations, and corrosive chemicals.

Simplistically, a glass-to-metal seal assembly consists of concentric rings of glass and metal which electrically isolate a central conductor terminal or pin from the terminal assembly body. The body is designed so that it will hermetically seal off a container when it is welded in place, thereby insuring integrity and reliability of the seal over time.

Basically, the manufacturing consists of processing the three components (the conducting terminal or pin, the glass and the body) into a final seal assembly. The specially formulated glass is crushed, powdered and then pressed or drawn into precisely shaped glass preforms or tubing. The metal components and glass preform are held in position by a graphite fixture while the glass softens and fuses to the metal in a controlled atmosphere oven.

Because of the large temperature difference between the furnace sealing temperatures and ambient, the thermal expansion relationship between the metals and glass is the primary consideration in designing a seal assembly.

With the various environments that glass-to-metal seals are used in, and the combination of the above-mentioned conditions, seals are designed specifically for the application to meet a wide range of unique requirements; whether temperature, electrical current, pressure, or corrosive. Two types of glass-to-metal seals can be designed: Compression seals, and Matched seals.

The combinations of metals most commonly found in battery applications as eyelets, lids, and pins dictates that virtually all glass-to-metal seals for lithium batteries are of the compression type. A compression seal is made by purposely mismatching the thermal expansions of the various materials so that the highest thermal expansion metal surrounds the glass which, in turn, surrounds the similar or lower thermal expansion metal pin. Consequently, as the assembly is cooled from the glass fusion temperature, the higher thermal expansion materials contract around the lower expansion materials with a large net compressive stress exerted between the pin and the metal body. Hermeticity is achieved through the compression fit between the components.

The compression seal takes advantage of the high tensile strength of metals and high compressive strength of glass. In addition to the compressive forces, there is generally a consideration of the chemical bonding of these seals. When certain pin, body, and glass materials are fused, there can be a chemical bonding which occurs. This provides additional integrity of a glass-to-metal seal, not solely resting on the compression forces to maintain hermeticity.

WHY GLASS-TO-METAL SEALS?

As mentioned previously, understanding the need for glass-to-metal seals in lithium battery applications can best be described by classifying the battery chemistries according to the nature of the cathode or electrolyte material. The four classifications typically mentioned are: solid cathodes, soluble cathodes, liquid electrolytes, and solid electrolytes.

Below is a brief overview of why glass-to-metal seals may find application within these classifications. Specifically, the reaction of materials often used dictates the use of a hermetic seal. Additionally, if a battery will see extremes of temperature or other elements in its environment, a hermetic seal is often used to isolate and minimize this exposure. Worth noting is that the variety of battery designs and chemistries precludes an exhaustive listing of the permutations and combinations of materials involved. These are general guidelines and there is overlap in some areas.

Solid Cathodes
These cathode materials are typically oxides or halides. Lithium cells of this design do not generally require a glass-to-metal hermetic seal since the cells do not operate under pressure of the reactant materials.

Solid Electrolytes
These chemistries may be organic or inorganic by nature. A common solid electrolyte system is lithium iodine, used principally within medical heart pace-maker applications because of its long shelf and service life. Glass-to-metal seals are commonly found in these applications in order to provide an extremely high level of reliability and integrity.

Soluble Cathodes/ Liquid Electrolytes
The reaction of these materials, typically liquids or gases, often causes the battery cell to remain under pressure. Because of the pressure built up within the cell, hermetic glass-to-metal seals have found widespread use in batteries of these types. Two common chemistries in this classification are lithium sulfur-dioxide, and lithium thionyl-chloride. A further aspect of these cells is that discharge currents can be very high, requiring additional features such as vents and thermal cutoffs to be designed into the battery.

SEALING MATERIALS

As stated previously, the combinations of eyelets, glasses and pins determine the integrity of a hermetic seal. Below are some common glass-to-metal seal combinations used in lithium battery applications. Of particular note is the selection of sealing glass chosen for specific lithium battery chemistries. Corrosion-resistant glasses are widely used in $LiSO_2$ and $LiSOCl_2$ systems today. These specially formulated glasses continue to grow in usage in other battery chemistries as manufacturers are designing systems for the highest reliability possible.

Body or Eyelet	Glass	Pin Material
Mild Steel	TA-23 Fusite MSG-12 CABAL-12	Molybdenum Tantalum Tungsten
304L SS	Fusite 435	446SS 52 Alloy Titanium

Above are some typical materials, including corrosion-resistant glasses, commonly used in glass-to-metal seals for lithium sulfur-dioxide and thionyl chloride batteries.

GLASSES

As mentioned earlier, the selection of a glass used in sealing applications is typically dependent on the body and pin materials that will be fused with the glass to form a seal. Lithium batteries, specifically certain lithium battery chemistries, require that a specially formulated corrosion-resistant glass be used to form a hermetic seal with long-life reliability.

Glass corrosion in a lithium battery system can lead to failure of the battery from short-circuiting across the seals and/ or from cracking of the glass, thereby permitting leakage of the battery electrolyte material. Short-circuiting occurs as corrosion forms on the glass and creates a conductive bridge across the glass, or insulator.

Early published research into the phenomenon of glass corrosion in lithium batteries was carried out by Sandia National Laboratories, a United States Department of energy facility. Sandia published a report in 1984 titled: "Ampule Tests to Simulate Glass Corrosion in Ambient Temperature Lithium Batteries". The test results reported by Sandia revealed that corrosion of the glass in lithium battery systems is sensitive to header polarization, stress, and configuration as well as glass composition.

In tests of two commercially-available glasses and a specially-formulated glass (TA-23), used in seals for lithium sulfur-dioxide and lithium thionyl-chloride batteries, Sandia concluded that the composition of the glass is probably the most important factor affecting glass corrosion of battery headers. These test results were validated by other firms in experiments to test parameters involved with glass corrosion of hermetic glass-to-metal seals.

Some of the corrosion-resistant glasses developed specifically for the lithium battery industry include Sandia Laboratories "TA-32" and "CABAL". Fusite has developed a variety of glasses for lithium battery applications, including: "MSG-12", "A-485", "425", and "435".

Some lithium chemistries used in combination with a glass-to-metal seal, such as lithium iodine, are generally more benign, or non-corrosive with respect to the glass. In these applications, the selection of a glass is most dependent on assuring a quality hermetic seal through evaluating the coefficients of thermal expansion of the body, glass, and pin materials.

BATTERY VENT DESIGNS

Virtually all batteries sold commercially have a vent of some type designed into them. Vents are extremely important components of lithium battery systems because of the volatile nature of certain lithium chemistries and the potential for disaster if the cell would burn or short circuit. For instance, an "F" cell lithium thionyl-chloride battery used for military applications has been estimated to have the potential of 1 and _ sticks of dynamite during a "catastrophic" failure.

The amount of pressure that can build within a battery cell is dependent on the chemistry of the cell and its construction. Certain chemistries, in combination with the physical design of the cell, have greater potential for hazard. Typically, higher-energy cells such as lithium sulfur-dioxide and lithium thionyl-chloride operate under greater pressure than other lithium battery chemistries, and must be designed with a vent as a critical component.

Vents are designed to expel the electrolyte material of the battery before internal pressures and temperatures build to cause an accident. As lithium has a fairly low melting point of approximately 180 degrees Centigrade, it is critical to expel the electrolyte quickly, before the lithium reaches its melting point. Lithium batteries generally incorporate one of three venting designs:

- Coining of the battery can
- Rupture disks, or
- A thin membrane integrated as part of a glass-to-metal seal. (Pressure Vent Lid)

Coining

Battery manufacturers have traditionally adopted "coining" or stamping a vent into the case or battery can. This coining creates a groove in the bottom or side of the can, or can be a convolution vent in the bottom of the can. This method has been effective across a wide range of battery types and designs. Generally, as pressures inside the battery increase, the coined area acts as a stress release point which bursts. This enables the pressure built up inside the battery to release, thereby averting a catastrophic failure. As mentioned earlier, some of the higher-energy lithium batteries can experience a tremendous build-up of pressure. The burst pressures from coining the battery can are sometimes unable to meet tight tolerance burst ranges necessary for these higher-energy systems. Additionally, coining often builds residual stresses into the battery can which may promote corrosion and accelerate the potential for failure of the cell. This has led to the use of the following types of vents for some of these applications.

Rupture Disks

Rupture disk technology provides a reverse buckling style disk, to be welded into an opening in the bottom of the battery can, in order to satisfy venting requirements. These disks can be made of nickel, inconel, or stainless steel material, and have found application in lithium batteries, fire extinguishers, compressed gas cylinders, refrigeration units, aerospace missiles, and aircraft wheels. While this technology offers closer control than coining methods over the range of burst pressures needed, one drawback is that an extra welding process is required in order to install the disk into a battery can.

BATTERY VENT DESIGNS CONTINUED

Pressure Vent Lid

Another method of producing a vent is to manufacture the vent design as part of the battery lid in a complete glass-to-metal seal and battery lid assembly. This vent is produced by chemically etching a portion of the battery lid and mechanically tuning the etched area to a specific depth in order to provide a reliable range of burst pressure protection. One of the main advantages of chemically etching the lid is to avoid the creation of residual stresses in the metal, thereby diminishing the potential for corrosion at the vent.

The Pressure Vent Lid is designed to allow a wide opening area to expel the electrolyte quickly. Since the lithium chemistries which typically have the greatest pressure buildup are the same chemistries that require a glass-to-metal seal, the design of these two components into one integrated unit offers the battery manufacturer a single component to weld into their can. This patented Pressure Vent Lid has been developed and commercialized by Fusite.

WELDING CONSIDERATIONS FOR GLASS-TO-METAL SEALS

There are two distinct welding operations related to glass-to-metal seals used in battery applications. One is welding of the glass-to-metal seal into a battery lid, and the second is welding of the battery lid into the can.

Because of the economies of operations of glass-to-metal sealing, increasing the density or number of parts to be run through the oven decreases the cost per part. For this reason, eyelets are often run through the oven to produce a glass-to-metal seal and are subsequently welded into a lid or battery cover assembly. This part is then ready to be welded into a battery can to produce a hermetic battery cell.

General concerns when welding glass-to-metal seals include the selection of materials to be welded, and the heat shock to the seal during the welding process. Similar metals should be chosen to be welded together whenever possible, as welding of dissimilar metals can contribute to corrosion at the weld interface. The second aspect, of critical importance, is the heat shock to the glass seal. if too much temperature is produced, or too much force applied during welding, the glass may crack or have residual stresses and cause the battery to lose hermeticity. For this reason, a significant level of expertise in design and welding is needed.

Two types of welding common to battery manufacturers are resistance and laser welding. After parameters of heat shock and weld cycle time have been established, welding of lids with glass-to-metal seals has been efficiently integrated into battery manufacturers' assembly and production operations.

THE FUSITE COMMITMENT

Fusite, a division of Emerson Electric Company, has been involved in the design and manufacture of hermetic glass-to-metal seals for over 50 years. With manufacturing operations in Cincinnati, Ohio, USA; Gotemba, Japan; Bao'an, PRC; Almelo, Holland; we are well positioned to serve the needs of battery manufacturers worldwide.

Fusite has vertically-integrated operations including: custom glass formulation and smelting, wire drawing, and metal stampings. This ability to manufacture and assemble every major component of our seals enables us to achieve better control of manufacturing, insuring quality throughout the process. Additional benefits to our customers comes in the way of eliminating middlemen and the markups associated with them. We are driven by the concept within Emerson Electric known as "Best Cost Producer". This means providing high-quality parts at the best cost possible.

Fusite began making glass-to-metal seals for lithium batteries in 1977, with the first Fusite seals going into pacemaker batteries. Changes in material specifications made by Fusite resulted in greatly reduced in-process losses at various pacemaker and battery manufacturers. Early customers who used Fusite seals found battery yields increased to 95-98% from 50% with competitors' products. Particular advances made in corrosion-resistant glasses and welding expertise of glass-to-metal seals enabled Fusite to deliver these increased yields.

From medical batteries, Fusite moved into serving the needs of battery manufacturers serving the military market. Again, superior strength and corrosion resistance provided for more reliable, durable battery systems. Following the success in the medical and military segments, the next move was to the commercial segment. The high quality reputation established in the medical and military markets has carried over to the commercial market as well. Our ability to produce millions of parts, as well as our strong engineering research and development focus on glass-to-metal seals, satisfies customers with a range of needs from R&D programs to full production volume requirements.

Fusite strives to offer our customers benefits through technological leadership, quality products, excellent service and support, and an ongoing research and development program to meet the needs of battery manufacturers worldwide. Our global presence and involvement with various lithium battery programs has helped Fusite stay at the front of technological advances.

FUSITE RESEARCH & DEVELOPMENT

Our focus on research & development is the key to meeting customer needs. Through early involvement with lithium battery manufacturers, Fusite has made significant innovations in development of corrosion-resistant glasses, new vent designs to meet the needs of higher-energy lithium systems, advanced welding methods, and process control of advanced manufacturing techniques to insure that we are the Best Cost Producer for your needs.

Through fundamental research in glass chemistry, Fusite has helped shape the evolution of glass-to-metal sealing technology. We make over 20 different glasses covering a range of thermal expansions for sealing to a variety of different metals. We also can create custom formulations for your most challenging applications. Fusite carefully adds proprietary modifiers to regulate the glass's coefficient of expansion or viscosity, improve molecular adhesion and corrosion resistance, and otherwise control material performance.

Through our extensive research and development efforts with various customers around the world, Fusite has developed a vent system that is integrated with a glass-to-metal seal as complete lid assembly for high energy lithium batteries. This "Pressure Vent Lid" highlights a strong global applications engineering department that has expertise and capabilities in working with customers to solve problems outside of traditional glass-to-metal seal needs. The vent system initially adopted to meet the U.S. military's contract needs for a thionyl-chloride battery system, is being used increasingly in other battery systems.

Advanced manufacturing and assembly methods, combined with Statistical Process Control, have enabled Fusite to stay in the forefront of delivering a high level of quality product to our customers. Through our continuing efforts focused on cost-reduction and automation we are able to provide and recommend opportunities for realizing cost reduction of production volume glass-to-metal seals.

With our expertise in welding, and our extensive laboratory facilities, we are able to meet a wide array of customers needs. Production sealing of various metals can be produced in exothermic, inert or vacuum atmospheres. This commitment to continually developing technologies associated with glass-to-metal seals provides the working knowledge necessary to meet customer needs across a range of battery chemistries, designs, and volumes. On the next page is a list of capabilities that Fusite offers.

FUSITE CAPABILITIES

- Glass formulation and development
- Environmental testing
    - -humidity
    - -salt spray
- Product test labs for:
    - -electrochemical corrosion
    - -ampule tests
    - -electrical (up to 10,000 V and 36,000 amps)
    - -physical properties
    - -chemical analysis
    - -metallographic
    - -differential thermal analysis (DTA)
- Welding
- Model shop capability (one at a time or pre-production quantities)
- Production sealing with exotic metals in exothermic, inert or vacuum atmospheres
- Plating (electrolytic and electroless)
- Oven capability
- Glass smelting, milling and granulation
- Glass pressing and sintering
- Brazing
- Epoxy coating
- Silicone rubber injection molding
- Wire drawing, forming and chopping
- Metal stampings
- Mass production of high technology components (over 1,000,000 parts a day)
- Glass sealing
- Glass smelting (4 grams to 400 lbs.)

FUSITE CWQI - COMPANY WIDE QUALITY IMPROVEMENT

Fusite has been actively involved in a Company Wide Quality Improvement process since July 1988. This is an ongoing process that provides the charter to continually improve quality throughout all functional areas and aspects of the organization. CWQI is Fusite's terminology for Total Quality Control, an ongoing process of quality improvement.

Here are some of the processes we are actively involved in monitoring and improving:

- Quality Awareness
- Training Committee
- Vendor Certification
- Market Awareness/ New Product Development
- Customer Satisfaction Committee
- Housekeeping & Safety, and
- Communications

From a standpoint of Market Awareness and New Product Development, Fusite actively solicits input and working relationships with our customers to meet their new product demands for tomorrow. Our Customer Satisfaction measures are carried out by a third-party research firm that asks customers for input across a variety of working relations with Fusite.

The outcome of Fusite's CWQI process is a heightened awareness on continuous quality improvement throughout all levels of the organization, strengthened by the support and direction of our top management.

SUMMARY

A number of aspects of glass-to-metal seals for lithium battery applications have been briefly discussed. There continue to be advances both in the state-of-the-art of battery manufacturing and design, as well as glass-to-metal sealing. This booklet has allowed us to take a snapshot of the industry at the present time and can act as a base of information from which to build.

In the future we expect to see great commercialization of lithium rechargeable battery systems in order to meet a growing array of end-user needs. The military is continually investing in new battery technologies in order to provide the greatest benefits possible to their users. Medical devices currently under development and testing should see tremendous growth in the coming years. With these activities well underway the future of the lithium battery marketplace looks very bright indeed.

ACKNOWLEDGMENTS

The employees of Fusite wish to thank our customers for their continuing trust and "investment" in Fusite as a partner in their business. It is the needs and requirements of our customers that provide the opportunity to continue research and development into glass-to-metal sealing and related technologies, our core business.

SUGGESTED READING

Partridge, J.H., "Glass-to-Metal Seals," Society of Glass Technology, Sheffield, England (1949).

Pask, J.A., "From Technology to the Science of Glass/ Metal and Ceramic/ Metal Sealing," Ceramic Bulletin, Vol. 66, No. 11, pp. 1587, 1592 (1987).

Pask, J.A. and R.M. Fulrath, "Fundamentals of Glass-to-Metal Bonding: VIII, Nature of Wetting and Adherence," Journal of American Ceramic Society, Vol. 45, No. 12, pp. 592-596 (1962).

Schmidt, J.J. and J.L. Carter, "Using Nitrogen Based Atmospheres for Glass-to-Metal Sealing," Metal Progress, July, 1985, pp. 29-34.

Lithium Battery Technology, Edited by H.V. Venkatasetty, John Wiley & Sons, New York, N.Y., 1984.

Gabano, J.P., Lithium Batteries, Academic Press, Inc., New York, N.Y., 1983.

Marincic, N., "High Energy Batteries," Chapter 9 in Lithium: Current Applications in Science, Medicine, and Technology, John Wiley & Sons, New York, N.Y., 1987.

Leedeke, C.J., Levy, S.C., Crafts, C.C., "Glass-to-Metal Seal Corrosion in Lithium-Sulfur Dioxide Cells", Power Sources 8 (1981), edited by J. Thompson.

Douglas, S.C., Bunker, B.C., Crafts, C.C., Quinn, R.K., "Ampule Tests to Simulate Glass corrosion in Ambient Temperature Lithium Batteries - Volume 2," Sandia Report, (Sand83-230V2), (1984).

Borom, M.P., and Pask, J.A., "Rose of "Adherence Oxides" in the Development of Chemical bonding at Glass-Metal Interfaces," Journal of the American Ceramic Society, Vol. 49, No. 1, pp. 1-6, January 21, 1966.

Volf, M.B., Technical Glasses, Sir Isaac Pitman and Sons, Ltd., London, England, 1961.

McLellan, G.W. and Shand, E.B., Glass Engineering Handbook, 3rd Edition, McGraw Hill, New York, N.Y., 1984.

Mayer, P., Topping, J.A. and Murthy, M.K., "Correlation between thermal expansion of glass and glass-to-metal adherence", Journal of The Canadian Ceramic Society, Vol. 43, pp. 43-46, 1974.

The articles below represent technical discussions of battery systems with evaluation of some of Fusite's corrosion-resistant glasses and Pressure Vent Lid.

O'Hara, T.J. III, "Glass Seal Corrosion Studies in Li-$SOCl_2$ Batteries," Proceedings of the 33rd International Power Sources Symposium, pp. 262-273, The Electrochemical Society, Pennington, NJ, 1988.

Ayers, A.D., Horvath, R.E., and Biegger, D.W., "Design of "F" Size Li/ $SOCl_2$ Cells For The BA-6598 Battery," Proceedings of the 33rd International Power Sources Symposium, pp. 198-211, The Electrochemical Society, Pennington, NJ, 1988.

Hart, D., Jones, R., and Krug, A., "Accelerated Aging of Hermetic Lithium/ Cupric Sulfide Cells," Progress in Batteries & Solar Cells, Vol. 8, pp. 80-83, 1989.

LITHIUM BATTERY INDUSTRY-RELATED ACTIVITES / TRADE GROUPS, PUBLICATIONS

Advanced Battery Technology Newsletter
Newsletter on battery developments and market activities.
C/o: Robert Morey & Associates
The Battery Bookstore
P.O. Box 30
Cooperstown, NY 13326
Phone (607) 547-5314

Progress in Batteries & Solar Cells
Various volumes available from the Battery Bookstore.

JEC Press, Inc.
Newsletter available through the battery bookstore.

Proceedings of the International Power Sources Symposium
Held biannually.
The Proceedings of the Symposium are published and distributed by The Electrochemical Society, Inc.,
10 South Main Street, Pennington, NJ 08534-2896

The International Seminar On Lithium Battery Technology & Applications
Sponsored by: Dr. S. P. Wolsky, Ansum Enterprises, Inc., and Dr. N. Marincic, Battery Engineering, Inc.
Contact: Dr. S. P. Wolsky
950 De Soto Rd., Suite 3B
Boca Raton, Florida 33432
Phone (407) 391-3544

Frost & Sullivan
Market Research Reports
The Lithium Battery Market In The U.S. (1986, and 1988)
The Lithium Battery Market In Europe (1988)
106 Fulthon St. New York, NY 10038
(212) 233-1080

Lithium Cell Database and Characterization Program
Department of the Navy
Naval Weapons Support Center
Crane, Indiana 47522

Lithium Batteries: Opportunities in an Expanding Market
Battelle Technical Inputs To Planning/ Report No. 53, 1987.

Annual Battery conference on Applications and Advances
Department of Electrical Engineering
California State University
1250 Bellflower Blvd.
Long Beach, CA 90840
Phone (212) 985-4605

FUSITE LOCATIONS

Fusite has been a global manufacturer of hermetic glass-to-metal seals for nearly fifty years. Our technical glass development is headquartered in Cincinnati, Ohio, in the United States of America, and we have the following locations to serve the global needs of battery manufacturers and our other customers.

Fusite
Division of Emerson Electric Co.
6000 Fernview Avenue
Cincinnati, Ohio 45212
USA
Phone: (513) 731-2020
Fax: (513) 631-6456

Fusite Japan
732 Fukasawa, Gotemba-Shi
Shizuoka-Ken, 412
Japan
Phone: 81-550-83-1555
Fax: 81-550-84-1022

Fusite BV
Konigweg 16
Almelo, Holland
Phone: 31-05490-15520
Fax: 31-05490-12468

Fusite Asia
5/F Pioneer Industrial Bldg.
213 Wai Yip St.
Kwun Tong, Kowloon
Hong Kong
Tel: +85-223-04-7778
Fax: +85-223-04-7780