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Key SEM evidence found in NTSB reports:

That extremely high temperatures likely occurred at local hotspots which were created by electric arcs that erupted inside certain GS Yuasa battery cells during Boeing 787 Dreamliner Logan airport thermal runaway incident

Sometimes a picture is worth a thousand words

Comments

about NTSB reports

Lewis Larsen

President and CEO
Lattice Energy LLC
April 30, 2013

"Facts do not cease to exist because they are ignored."

Aldous Huxley in "Proper Studies" 1927

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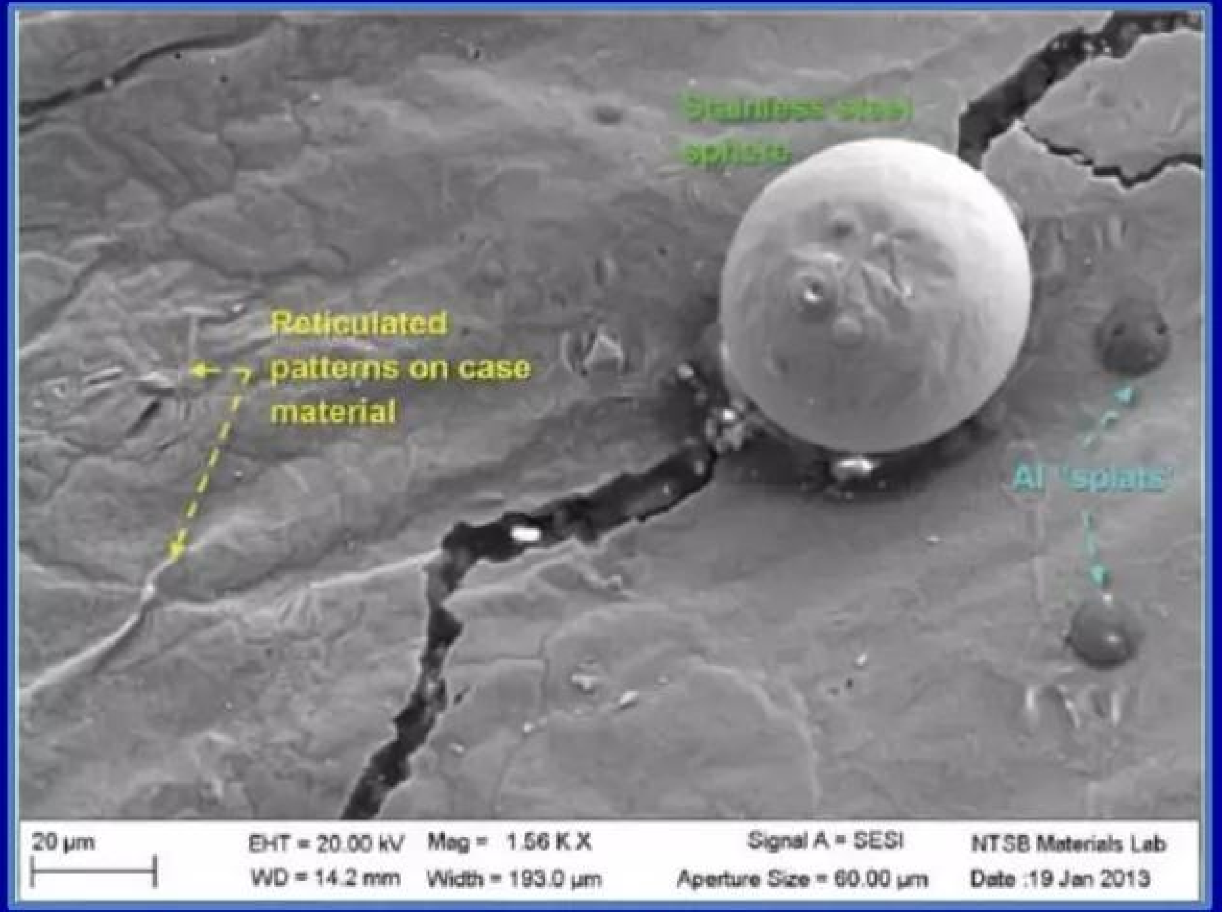
http://www.slideshare.net/lewisglarsen

Scanning electron microscope (SEM) image



Presence of perfect stainless steel microspheres in battery debris suggests that local temperatures were > 3,000^{o} C

Scanning electron microscope (SEM) image

Perfect stainless steel microspheres are created by condensation of droplets from a vapor phase; similarities to laser ablation

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Summary

Creation of stainless steel microspheres implies local hotspots > 3,000° C

- ✓ When NTSB scientists investigated charred debris found inside the ruined Logan GS Yuasa battery cells with a scanning electron microscope (SEM), near locations where electric arcs (internal short circuits) had obviously occurred they discovered notable numbers of *perfect (microscopic) stainless steel microspheres* lying amongst the disorganized rubble of various battery materials

- ✓ What most technical people following the NTSB's investigation may not have fully appreciated was that these beautiful little metallic microspheres are 'smoking gun' evidence for vaporization and condensation of stainless steel comprising the battery cell casing in local hotspots created by high-current, low voltage electric arcs, i.e., one or more internal shorts likely occurred inside GS Yuasa battery cell #5

- ✓ This experimental data implies that the local temperature of the battery casing's Type 304 stainless steel hotspots directly exposed to the internal short's arc plasma didn't just get to the melting point of such steel (~1,482 degrees C) --- instead these local areas *got all the way up to the boiling point of stainless* (> 3,000 degrees Centigrade), were turned into a gaseous vapor (expanding in volume by >50,000 x in the process of vaporizing); solid steel then recondensed from hot metallic vapor in the form of perfect nanoscale steel spheres as portions of the super-hot metallic Fe-alloy vapor quench-cooled. We will now briefly discuss this important factual data

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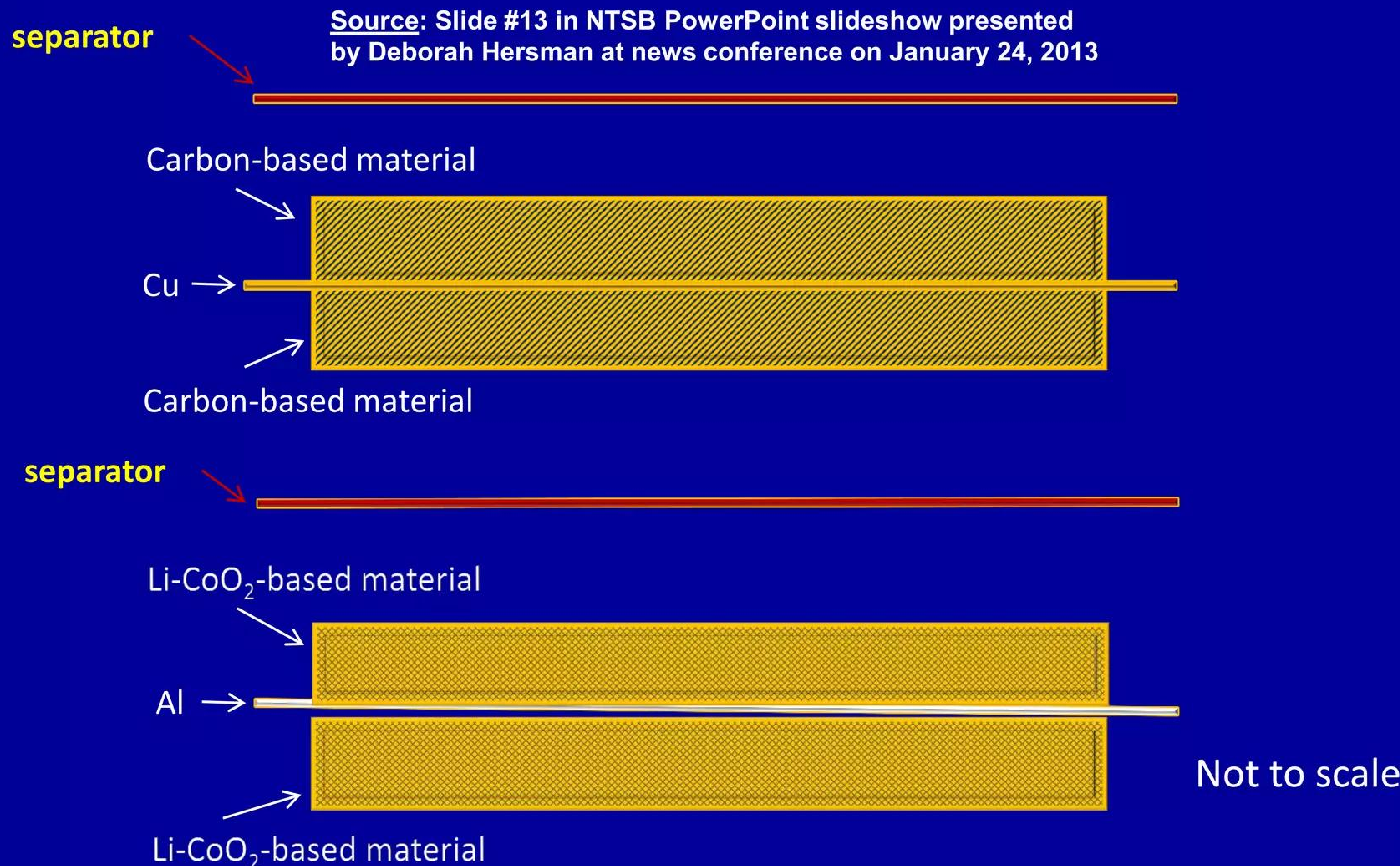
Dreamliner GS Yuasa battery: electrode construction



Copy of source document: http://www.ntsb.gov/investigations/2013/boeing_787/JAL_B-787_1-24-13.pdfs

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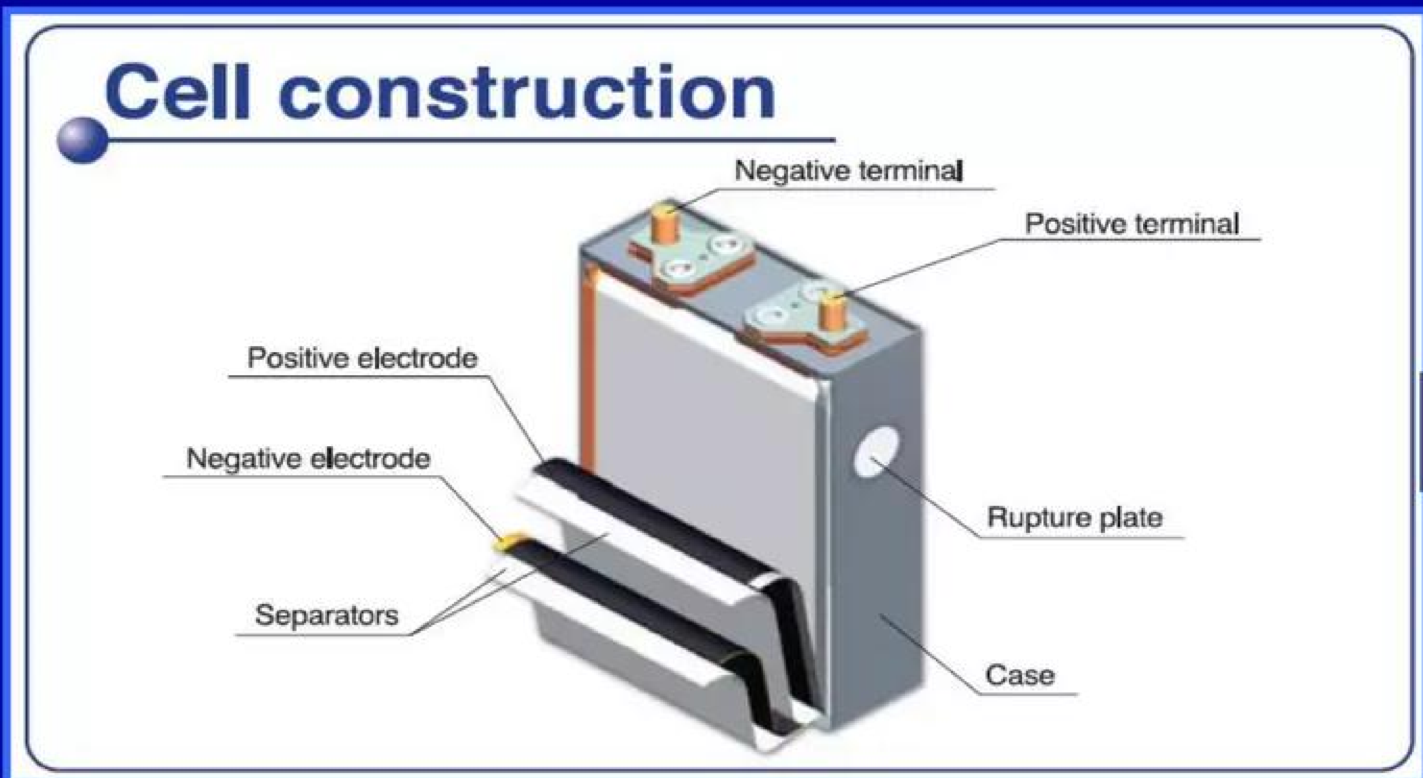
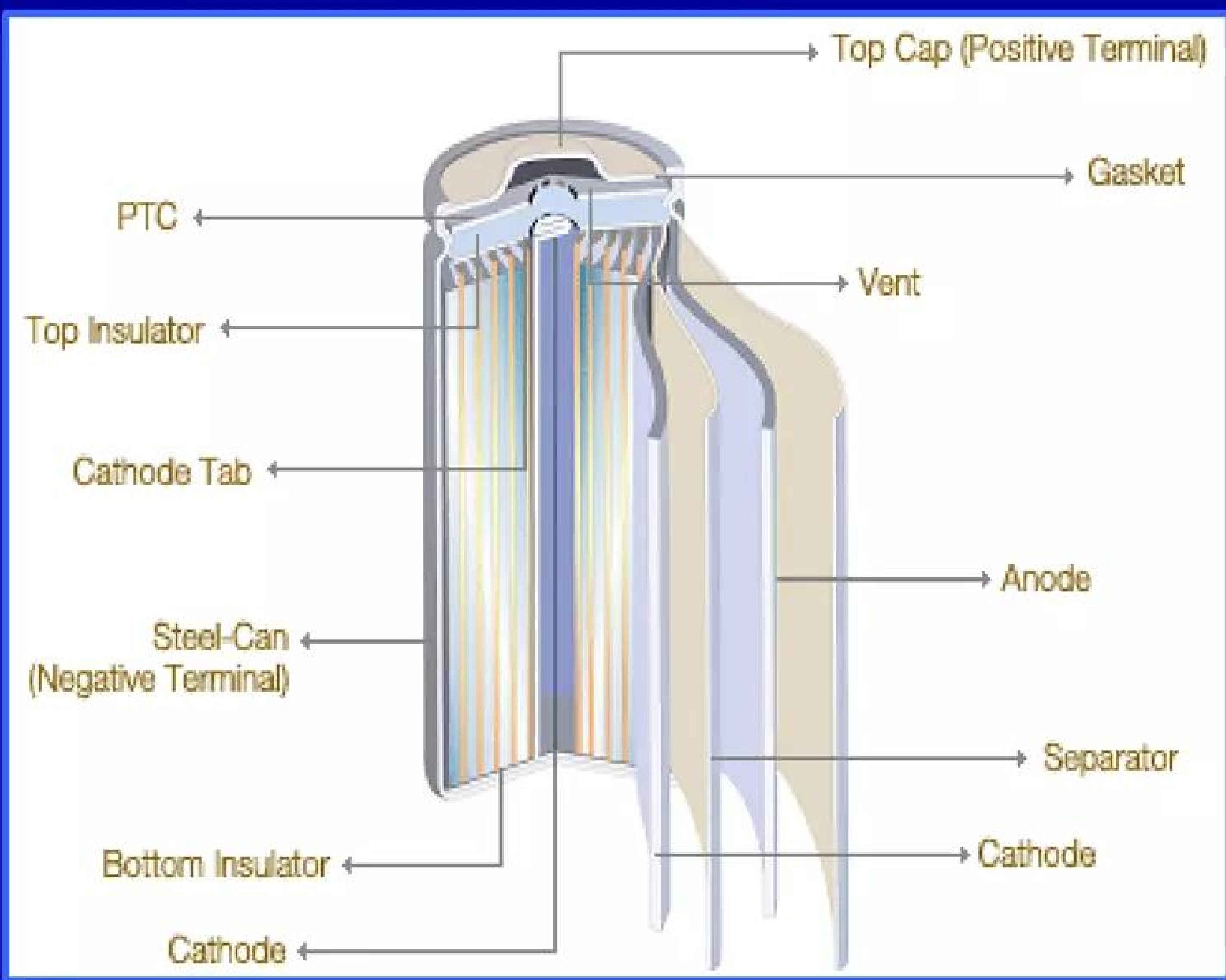
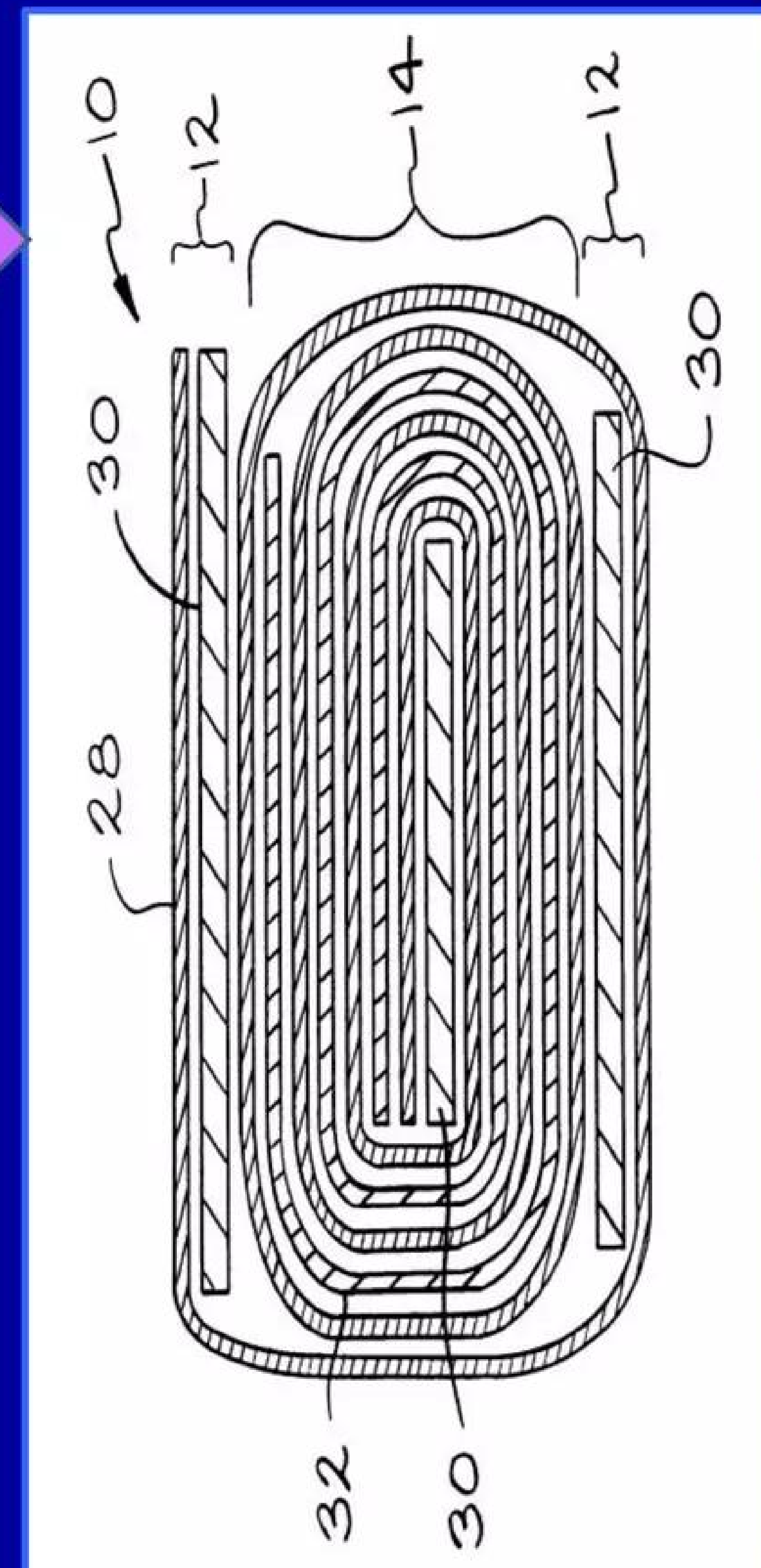
Internal organization of GS Yuasa battery cell



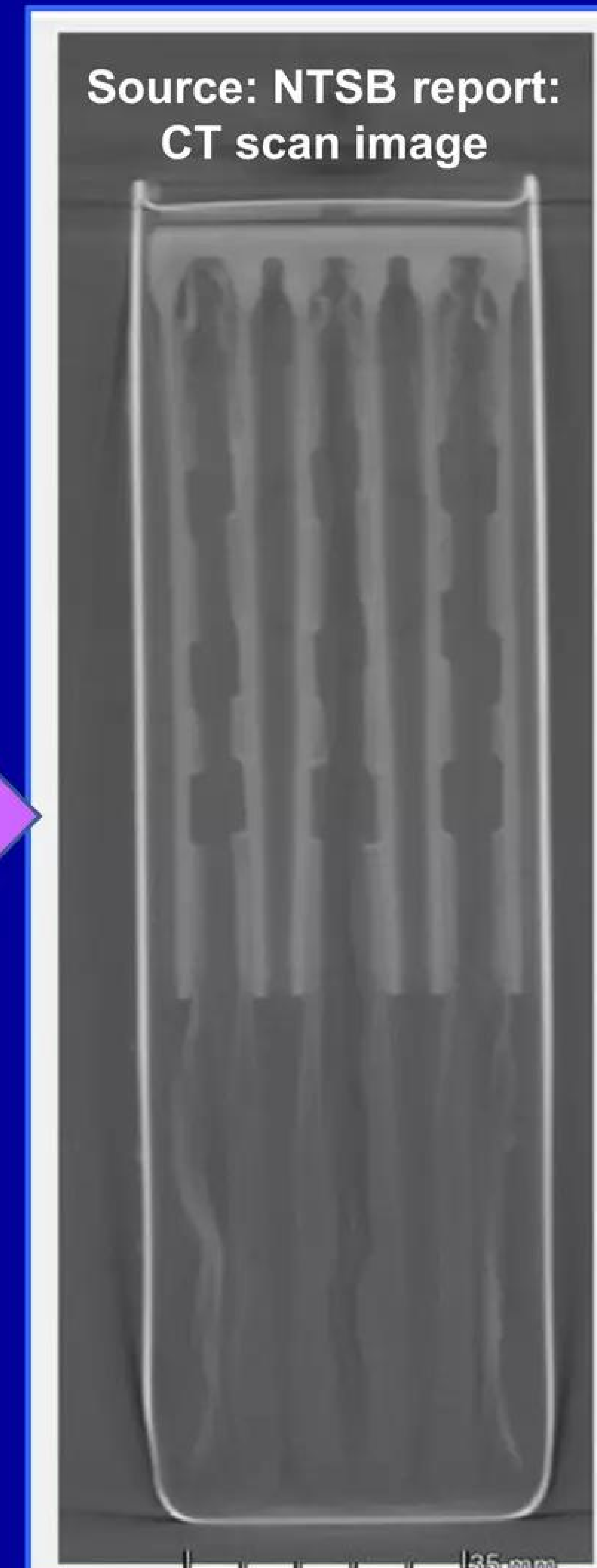
Source: GS Yuasa - prismatic cell *a la* 787 Dreamliner battery



Source: SONY "jelly roll" cell - commodity Lithium-ion battery



Source: USPTO – sample patent drawing for prismatic battery cell



Source: NTSB #13-013 February 19, 2013

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Hole punched through internal electrode by electric arc

Hole

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Excerpt from NTSB report

Source: page #18 in NTSB – Materials laboratory factual report No. 13-013 dated February 19, 2013

DCA13IA037 Report No. 13-013
Page No. 18

during cooling. There were a variety of spherical particles found embedded in the combustion compounds in hole 1 (see Figure 66). The composition of the spheres was consistent with the cell case material (stainless steel). Spherical particles on or near resolidified areas is consistent with the melting, separation, and solidification processes typical of electric arc damage. For reference, the temperatures that would be required to melt aluminum alloys are in excess of 1250° F, while those required to completely melt this stainless steel alloy are typically in excess of 2700° F.

Examination of the three other holes on the C5 cell case revealed similar results. Figure 67 and Figure 68 display holes 2 and 3, respectively, from the interior of the case. Of note was the spherical globule located near hole 3 on the exterior of the case. The globule was consistent with type 304 stainless steel, and it exhibited a reticulated surface pattern. The case material was wrinkled near hole 3. There were also indications of metallization “splats” of aluminum alloy near the hole (Figure 69). The flattened shape of this metallization is consistent with the case material being near the molten aluminum temperature during deposition. Near hole 4, a depressed lamellar structure was observed in the case material (Figure 70). This surface morphology is consistent with incipient melting of the material, which occurs at temperatures high enough to cause some of the alloy constituents to liquefy.[8]

Copy of source document: http://www.ntsb.gov/investigations/2013/boeing_787/docket_documents/787_docket_doc2.pdf

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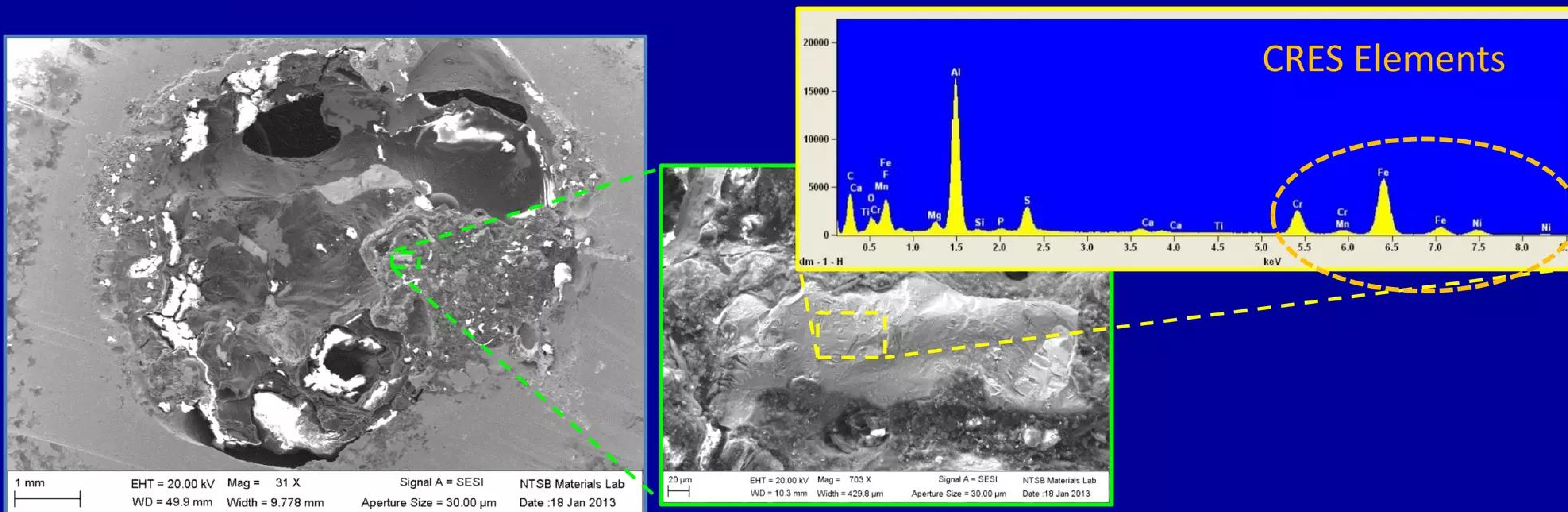
Excerpt directly from NTSB presentation

Source: Slide #28 in NTSB PowerPoint slideshow presented by Deborah Hersman - January 24, 2013



- Finding: electrical arc between battery cell and inside of battery case
- Not believed to be initiating event

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Electric arcs punched 4 holes thru battery cell #5 casing

Lattice note: battery casing material is stainless steel

Source: page # 78 in NTSB – Materials laboratory factual report No. 13-013 dated February 19, 2013

Lattice comment: electric arcs from battery case definitely crossed 0.2” air gap and discharged into (blue painted) aluminum battery system enclosure (which is highly conductive compared to stainless steel). If this were just air, would require ~15 kilovolt potential for arc to cross gap. Since it was hot inside case during Logan fire, intervening gas was very likely more conductive with ionization present. Nonetheless, arcs could have been somewhere in kV range

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SEM images: stainless steel microspheres - NTSB report

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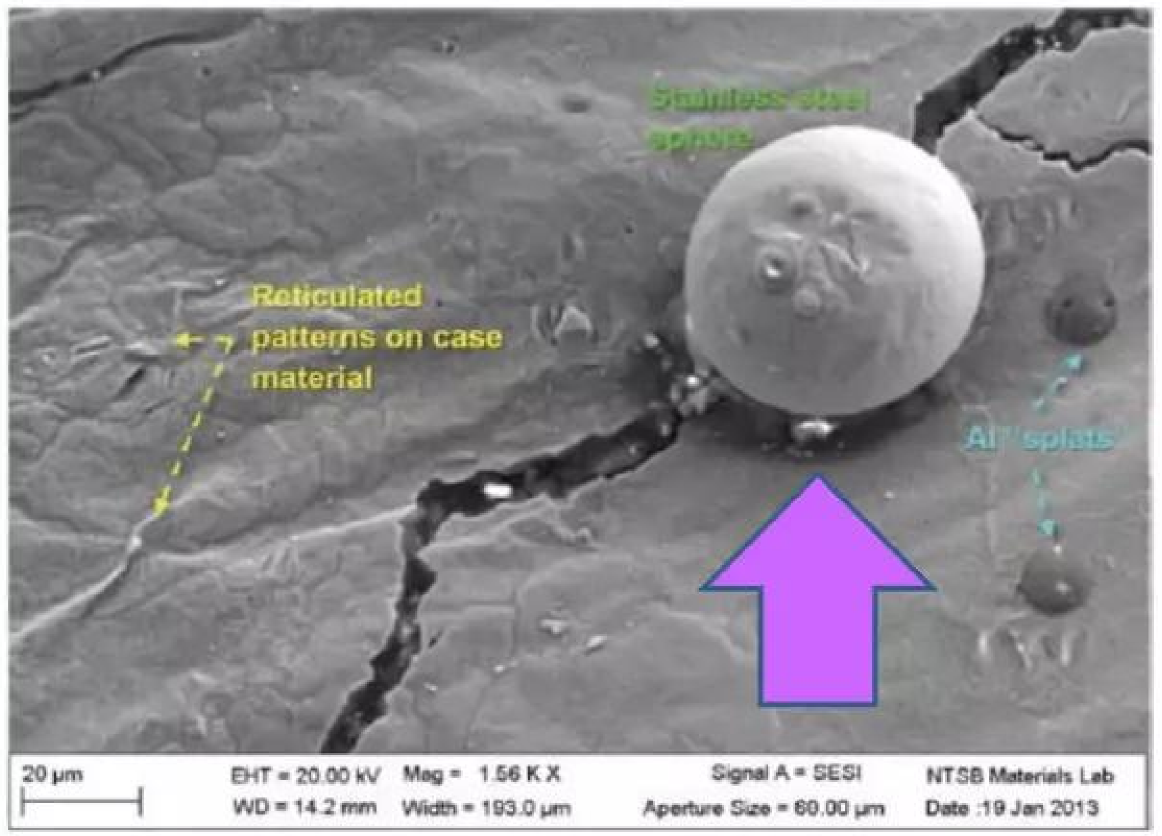

Figure 69. SEM micrograph of a spherical particle of stainless steel found near the exterior side of hole 3.

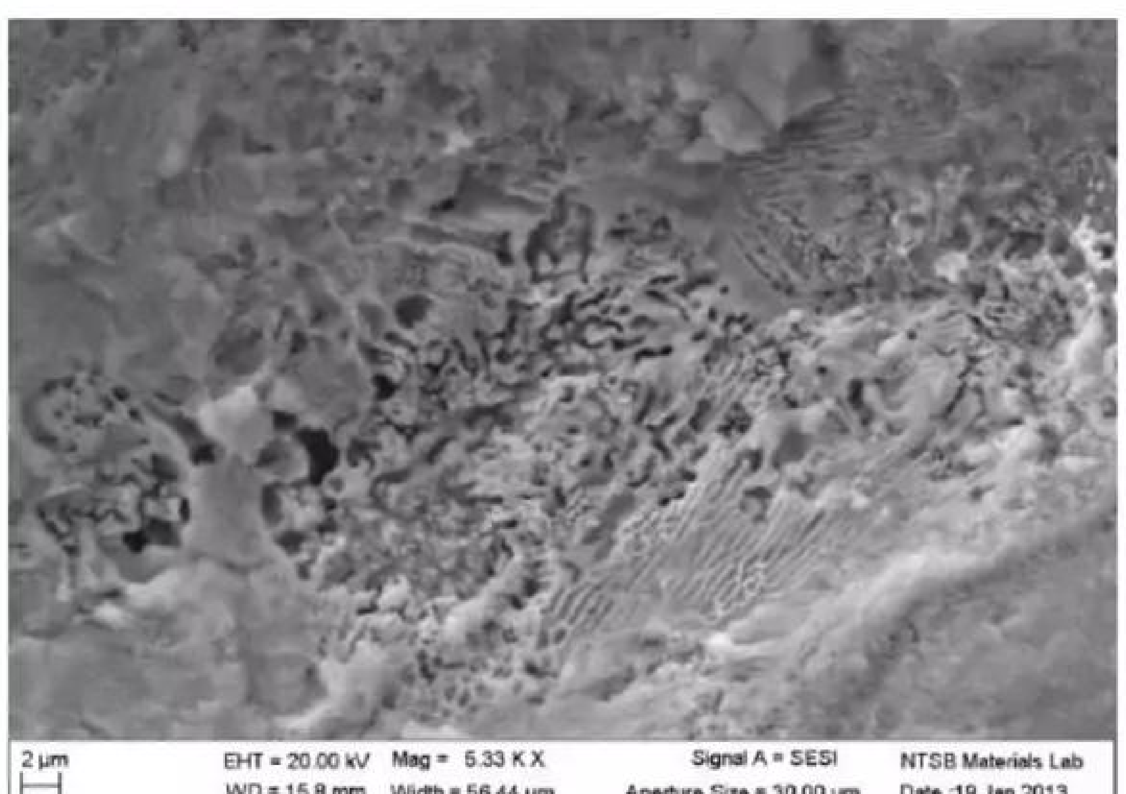

Figure 70. SEM micrograph of lamellar structure consistent with incipient melting near the exterior of hole 4.

Purple arrows added by Lattice

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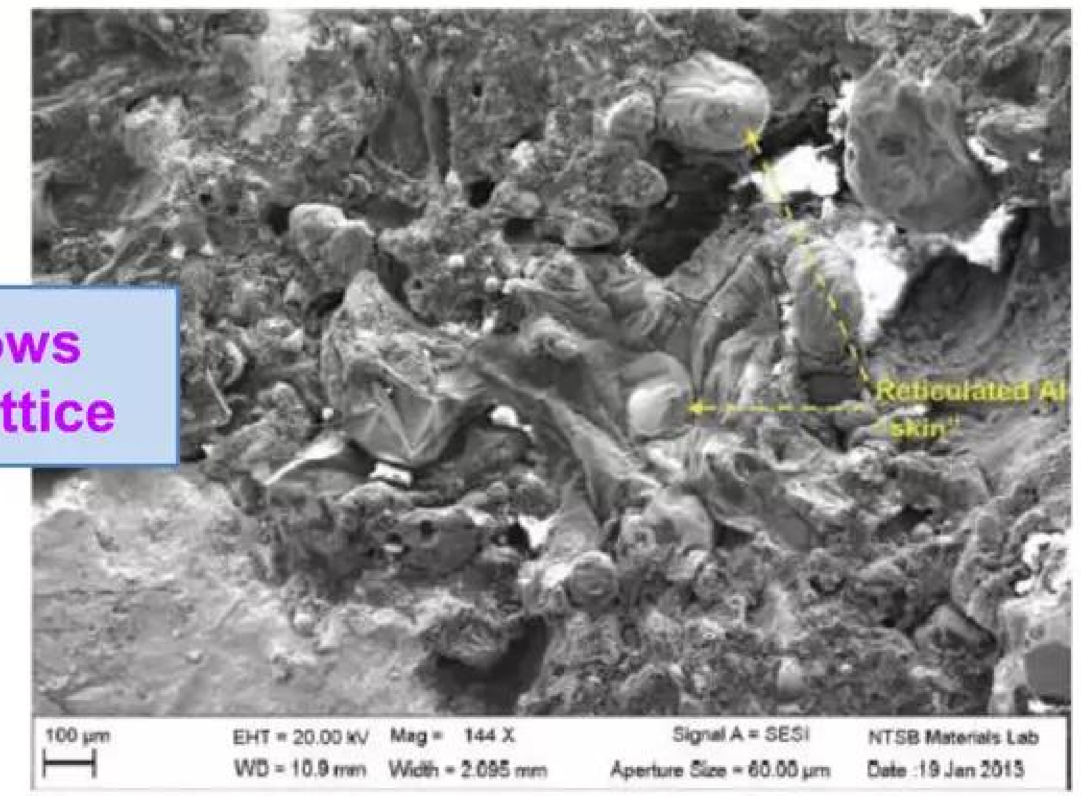

Figure 65. SEM micrograph of hole 1 from the exterior of the C5 cell case. This region exhibited rounded protrusions consistent with resolidified steel encompassed by an external layer of aluminum alloy.

Figure 66. SEM micrograph of steel sphere embedded in combustion products in the interior of hole 1 on the C5 cell case.

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Low-voltage electric arcs reach enormous temperatures

Source: PhD Thesis -"*Modeling and Simulation of Low Voltage Arcs*"
by Luca Ghezzi, Technical University of Delft - Netherlands (2010)

Excerpted directly from Ghezzi's thesis:

The arc core reaches temperatures in the order of $10\,000 - 20\,000\,K$, but its surrounding zone, being in contact with the polymer, is considerably colder, with temperatures around $3\,000 - 5\,000\,K$. This temperature range is of the order of, or sometimes exceeds, some typical dissociation temperatures of polymer components, such as that of C_2H_4 ($1\,400\,K$), CH ($3\,700\,K$), C_2H ($4\,500\,K$) and CO ($7\,000\,K$) [139]. More than conduction or convection, heat is transferred from the arc to the polymer by means of radiation. Therefore, the thermal coupling is better if the spectral band of emission from the arc plasma and from the metal contacts and the spectral band of absorption of the polymer coincide or overlap [153].

To obtain a copy:
http://www.google.com/url?sa=t&rct=j&q=%E2%80%9Cmodeling%20and%20simulation%20of%20low%20voltage%20arcs%E2%80%9D%20luca%20ghezzi%20pdf&source=web&cd=1&cad=rja&ved=0CC4QFjAA&url=http%3A%2F%2Frepository.tudelft.nl%2Fassets%2Fuuid%3Addf219d8-5572-45c5-9249-aacbb68683cd%2FModeling_and_Simulation_of_Low_Voltage_Arcs.pdf&ei=vQeAUe3XCovO9ATNjYCoCQ&usg=AFQjCNGnoKc_QU7EMxau7xNIIz-tL8dceg&bvm=bv.45645796,d.eWU

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Similar results can occur during laser ablation of surfaces

Spherically-shaped droplets can be created in such processes

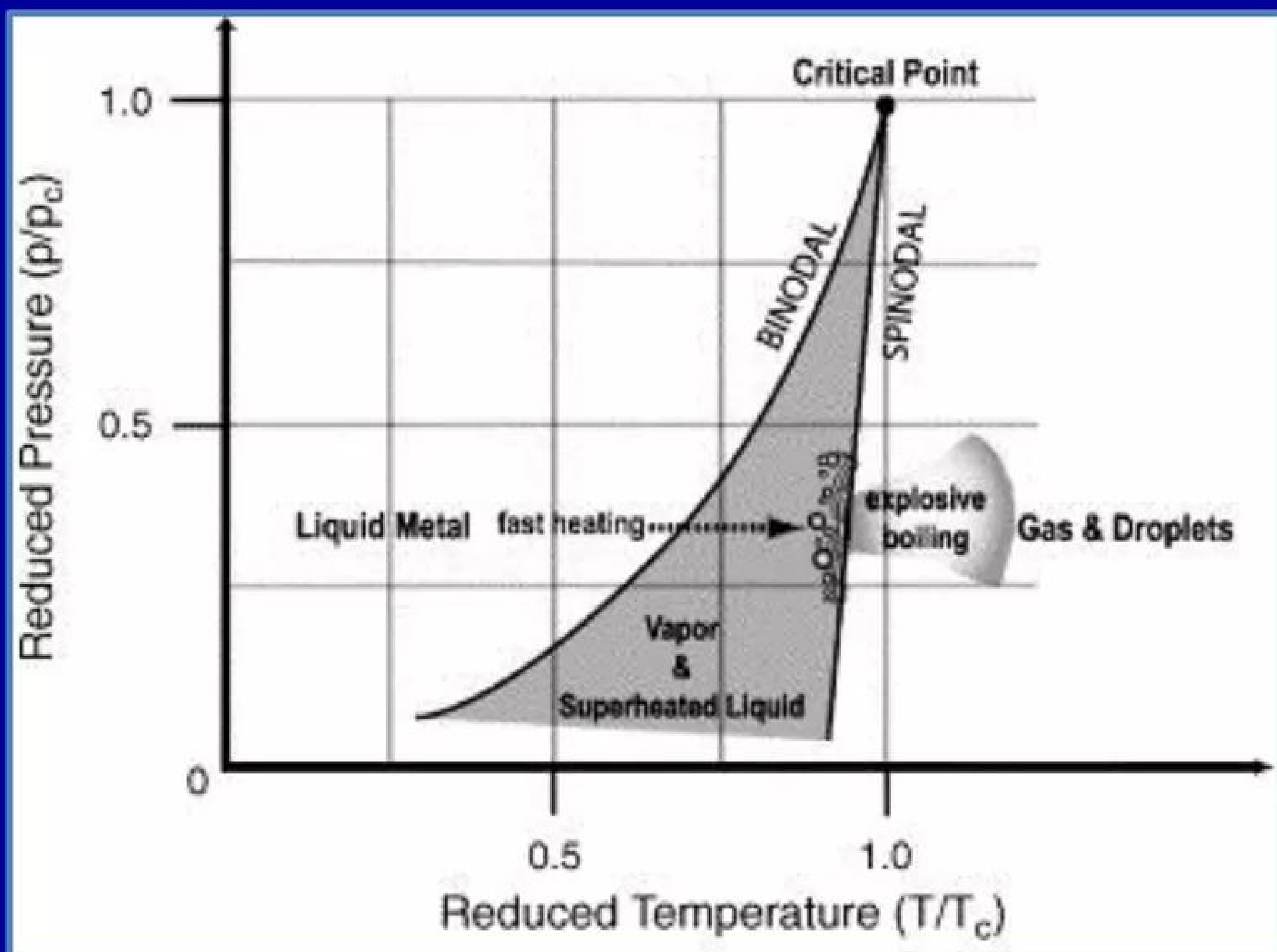

Fig. 1. Phase stability diagram of a liquid metal near the critical point. For fast heating, as obtained during *ns* laser ablation, the melt can be pushed close to critical conditions (superheating), which favors the realization of explosive boiling

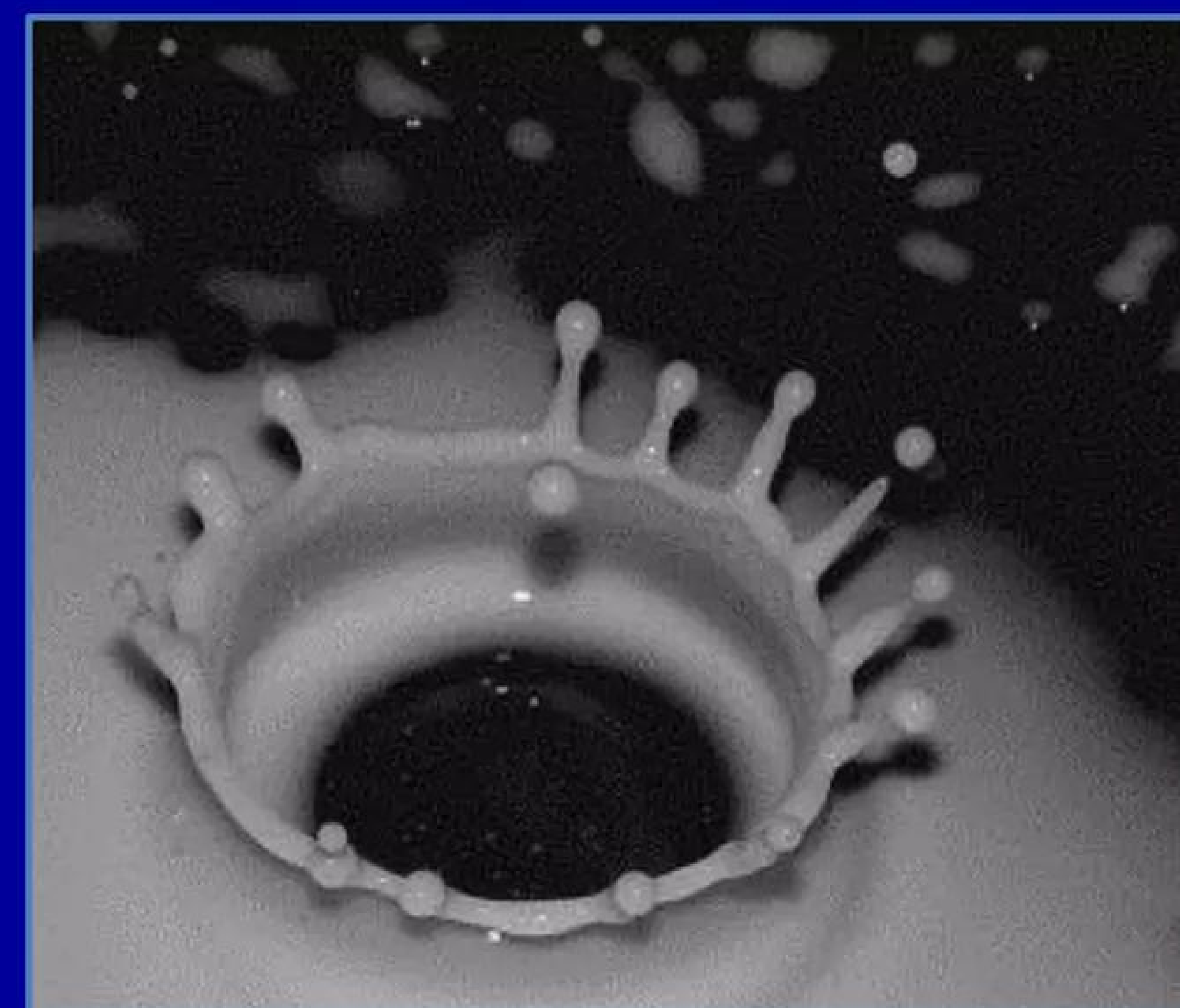

Fig. 2. Schematic visualization of the hydrodynamic evolution of a fluid system under and impulse stress (here milk). Note the non-deterministic formation of jets at the sides and their break-up into droplets. From Ref. [58].

Excerpted and quoted directly from:

"*Multiplicity and contiguity of ablation mechanisms in laser-assisted analytical micro-sampling*"
D. Bleiner and A. Bogaerts
***Spectrochimica Acta Part B: Atomic Spectroscopy* 61 pp. 421 - 432 (2006)**
http://www.sciencedirect.com/science/article/pii/S0584854706000437

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Similar results can occur during laser ablation of surfaces

Spherically-shaped droplets can be created in such processes

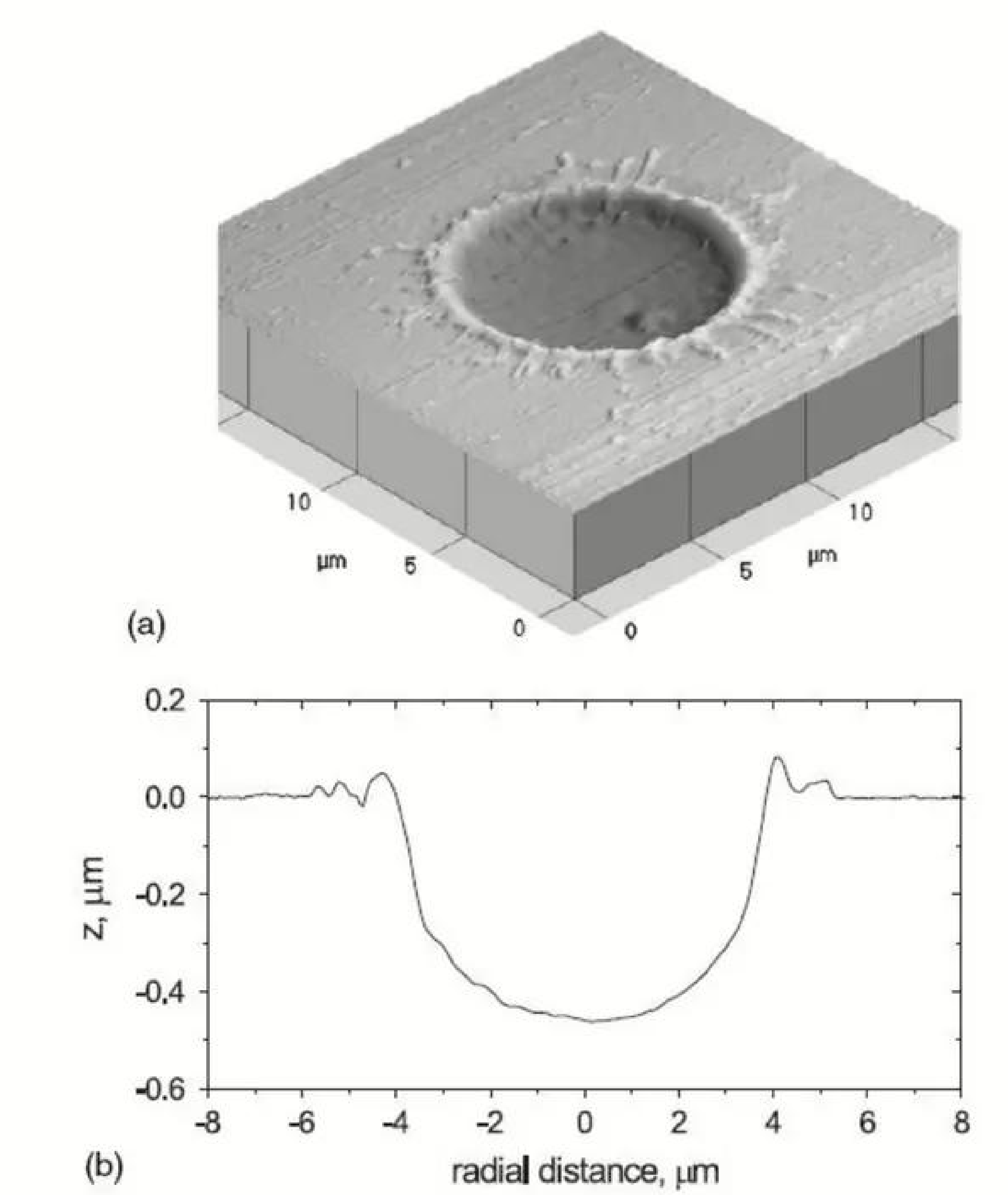


Figure 3. An AFM study of a single crater ablated with a 200 fs and 780 nm laser pulse of $F_0^{av} = 12.6\ \mathrm{J\,cm^{-2}}$. (*a*) The AFM image. (*b*) The ablation profile at the centre-line of the crater. The radius of the beam spot size is $w_0 = 5.9\ \mu$m.

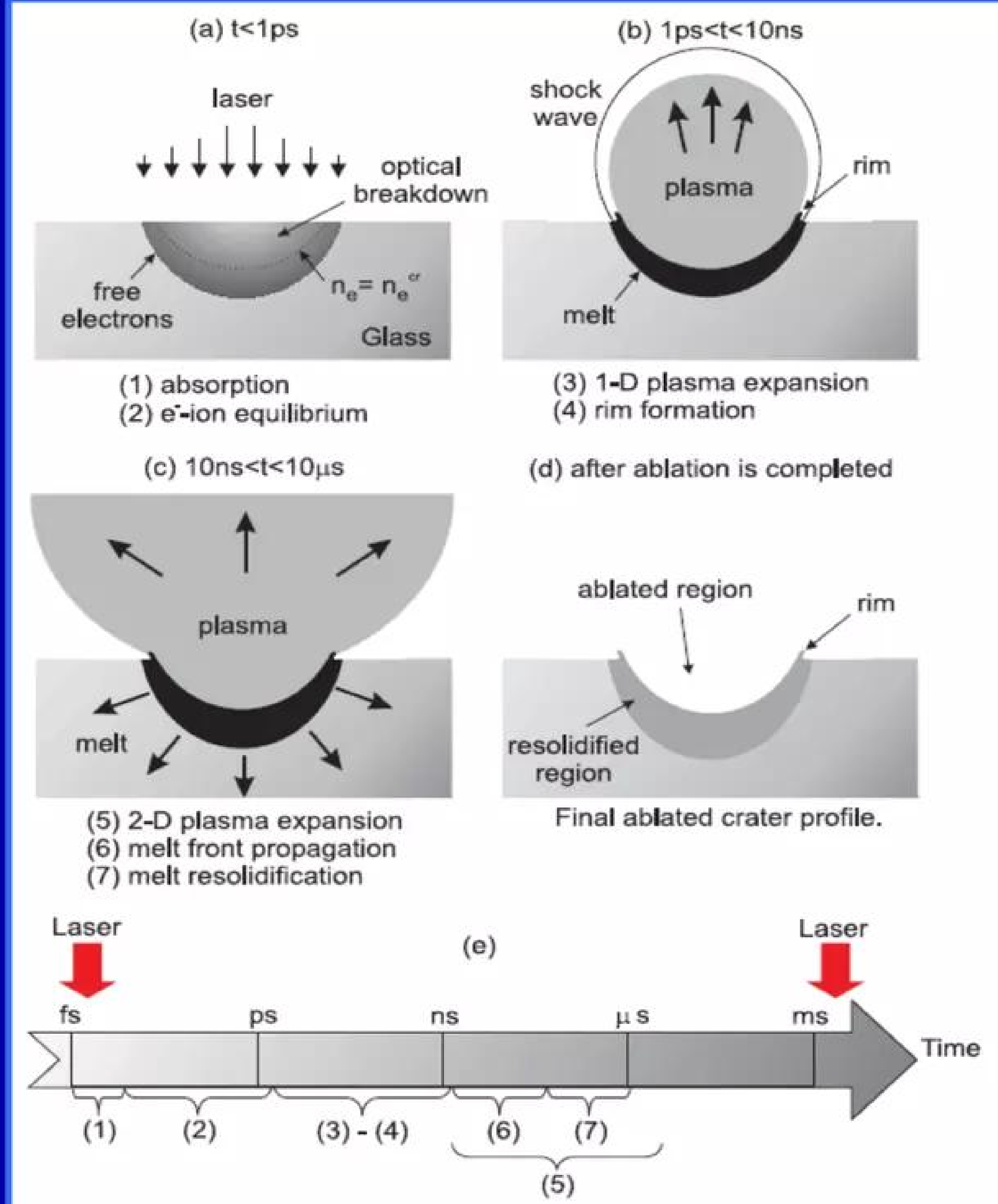


Figure 4. A schematic description of ablation process of glass with a femtosecond laser pulse (*a*)–(*d*) and time scales associated with various processes (*e*).
(This figure is in colour only in the electronic version)

Excerpted and quoted directly from:

"*Thermal and fluid processes of a thin melt zone during femtosecond laser ablation of glass: the formation of rims by single laser pulses*", A. Ben-Yakar *et al.*, *Journal of Physics D: Applied Physics* 40 pp. 1447 - 1459 (2007)
http://www.stanford.edu/~rlbyer/PDF_AllPubs/2007/423.pdf

Cathodic arc discharges and LENRs are very energetic

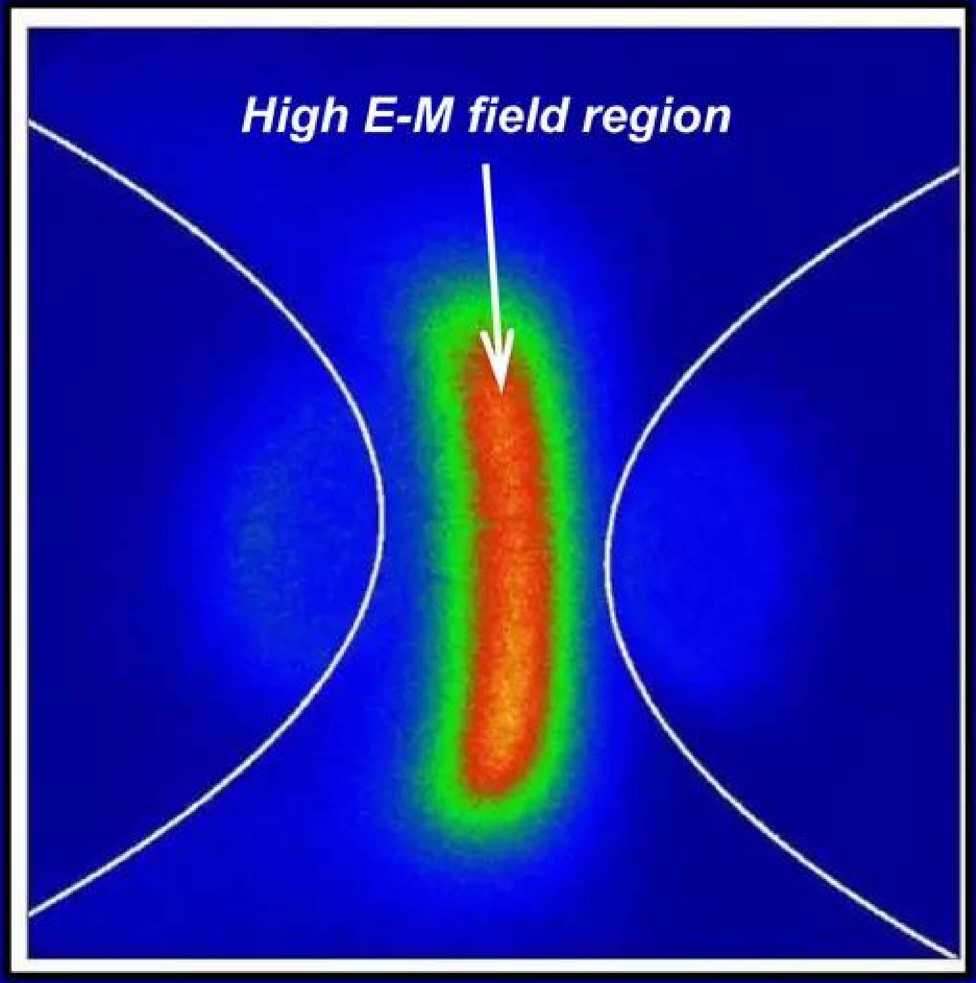
Amazingly, details of electric arcs are still imperfectly understood

Electrical breakdown and arc discharges (i.e., sparks, shorts):

Although they have been studied for 200 years, in many ways electric discharges are still not all that well understood. Recent measurements (2007) of spark discharge in low-pressure Xenon gas using rapidly pulsed lasers has helped better understand the still enigmatic process:

"A spark flying between a metal doorknob and your hand is an intricate chain of electrical events … researchers report the first direct measurements of the sharply changing electric fields that pave the way for a visible flash in a precisely controlled laboratory arc. Their results provided concrete detail in an area where theoretical modeling remains scanty, and may offer a way to study electrical discharges in settings ranging from plasma televisions to lightning strikes ... Whether it's a lightning bolt or the spark inside a bad switch, the process is the same: The voltage across a region of air becomes large enough to drive an electric current by creating a plasma. The process starts when a few stray electrons--accelerated by the electric field--knock into atoms and liberate more electrons, which continue the process. In carefully designed lab experiments the region between a pair of electrodes fills with plasma smoothly, starting at the positive end, with a wave front that sweeps quickly across to the negative end. At the leading edge of this so-called ionization front is a narrow band of enhanced electric field, according to theory and indirect experiments, but theorists only vaguely understand what determines the field's profile. Nor have experimenters been able to map the field profile directly, because inserting metal probes distorts the discharge. Researchers have tried to infer field strengths from the glow following the breakdown, but that light is feeble and only appears once the ionization is well under way.

Source: D. Monroe, *Physical Review Focus*, "Xenon on the verge of an electric breakdown," Feb. 9, 2007 URL = http://focus.aps.org/story/v19/st4



E. Wagenaars/Eindhoven Univ. of Tech

Reference: E. Wagenaars, M. Bowden, and G. Kroesen, "*Measurements of electric field strengths in ionization fronts during breakdown*," *Physical Review Letters* 98 pp. 075002 (2007)

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Cathodic arc discharges and LENRs are very energetic

Field emission is precursor to surface breakdown and electric arcs

Field electron emission (associated with very high, often rapidly changing local E-M fields):

"Field emission (FE) (also known as electron field emission) is an emission of electrons induced by external electromagnetic fields. Field emission can happen from solid and liquid surfaces, or individual atoms into vacuum or open air, or result in promotion of electrons from the valence to conduction band of semiconductors. The terminology is historical because related phenomena of surface photoeffect, thermionic emission or Richardson-Dushman effect and 'cold electronic emission', i.e. the emission of electrons in strong static (or quasi-static) electric fields, were discovered and studied independently from 1880s to 1930s. When field emission is used without qualifiers it typically means the 'cold emission'."

"Field emission in pure metals occurs in high electric fields: the gradients are typically higher than 1000 volts per micron and strongly dependent upon the work function. Electron sources based on field emission have a number of applications, but it is most commonly an undesirable primary source of vacuum breakdown and electrical discharge phenomena, which engineers work to prevent."

"Field emission was explained by quantum tunneling of electrons in the late 1920s. This was one of the triumphs of the nascent quantum mechanics. The theory of field emission from bulk metals was proposed by Fowler and Nordheim. A family of approximate equations, 'Fowler- Nordheim equations', is named after them."

"In some respects, field electron emission is a paradigm example of what physicists mean by tunneling. Unfortunately, it is also a paradigm example of the intense mathematical difficulties that can arise. Simple solvable models of the tunneling barrier lead to equations (including the original 1928 Fowler-Nordheim-type equation) that get predictions of emission current density too low by a factor of 100 or more. If one inserts a more realistic barrier model into the simplest form of the Schrödinger equation, then an awkward mathematical problem arises over the resulting differential equation: it is known to be mathematically impossible in principle to solve this equation exactly in terms of the usual functions of mathematical physics, or in any simple way. To get even an approximate solution, it is necessary to use special approximate methods known in physics as "semi-classical" or "quasi-classical" methods. Worse, a mathematical error was made in the original application of these methods to field emission, and even the corrected theory that was put in place in the 1950s has been formally incomplete until very recently."

Source: Wikipedia article titled "Field electron emission" as of July 10, 2010 http://en.wikipedia.org/wiki/Field_electron_emission

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Cathodic arc discharges and LENRs are very energetic

Seidman: *"… highest power density commonly found in Nature"*

D. Seidman's candid comments on field emission and breakdown in a grant proposal written back in 2005:

Dave Seidman is the Walter P. Murphy Professor of Materials Science and Engineering at Northwestern University in Evanston, IL, and leads the Seidman Research Group at NWU's Center for Atom-Probe Tomography (NUCAPT) - http://arc.nucapt.northwestern.edu/Seidman_Group

Prof. Seidman has a unique knowledge of high surface electric fields, field emission, and arc discharges as a result of his many years of work with atom-probe tomography (APT) which uses nanoscale local electric fields of 10^{10} V/m *and higher* to image the structure and analyze the chemical composition of surfaces on near atomic-scales (see image to right courtesy of Imago, Inc., a manufacturer of APTs)

Quoting (*ca.* 2005), "NUCAPT is among the world leaders in the field of three-dimensional atom-probe microscopy, particularly as result of the recent installation of a LEAP microscope, manufactured by Imago Scientific Instruments. Currently only three other LEAP microscopes, with a comparable performance, exist throughout the world."

Readers will find a boldness and blunt candor in Seidman's insightful remarks to follow that tend to be absent in published refereed papers

Seidman's quoted remarks were made in the context of a publicly posted 2005 grant proposal: Seidman, D., and Norem, J., "Experimental study of high field limits of RF cavities"

Please see source URL:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

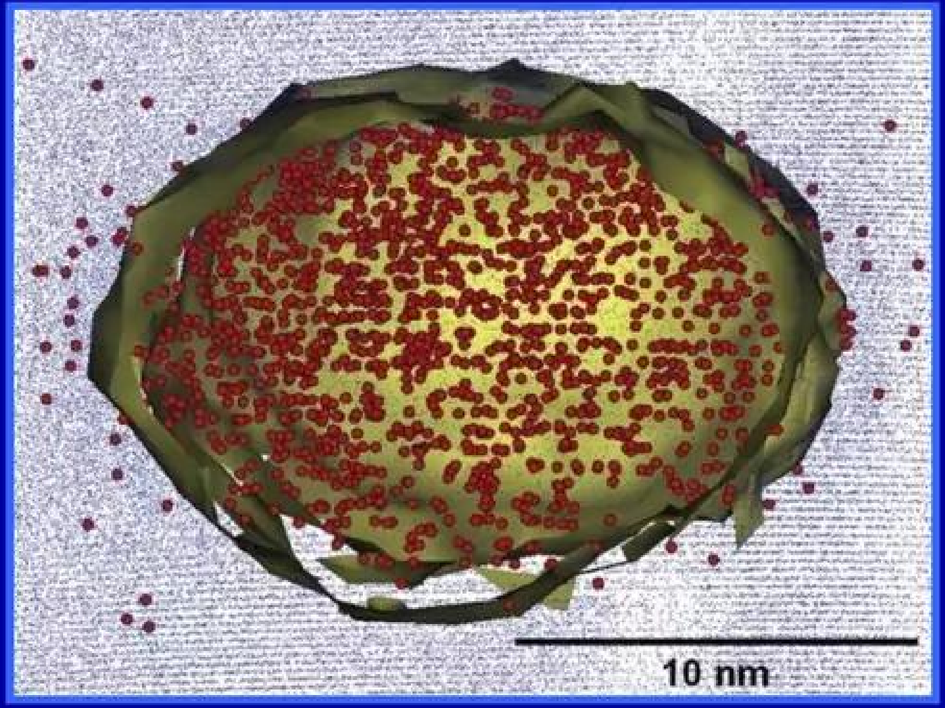

Image: Larson & Kelly, Imago, Inc., local-electrode atom probe image of ordered $L1_2$ Al_3Sc precipitate in aluminum matrix (Al – blue, Sc – red). The <200> planar spacing of the crystalline Al lattice (spacing ~0.2nm) is evident and contrasts with the <100> planar spacing (~0.4 nm) of the Al_3Sc precipitate. Alloy provided by van Dalen, Dun, and Seidman

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Cathodic arc discharges and LENRs are very energetic

Seidman: *"… highest power density commonly found in Nature"*

<u>Seidman's comments *circa* 2005</u>:

"[Electric arc] breakdown at surfaces was discovered by Earhart and Michelson, at [the University of] Chicago, in 1900 … While checking the new 'electron' theory of gas breakdown at small distances, they discovered that there were two mechanisms present, at large distances gas breakdown dominated, and at small distances [i.e., on small length-scales] breakdown of the surface was correctly identified as the mechanism. The break point where the two mechanisms met, at atmospheric pressure, occurs at about 300 V … This was confirmed 5 years later by Hobbs and Millikan, and is consistent with modern data on vacuum breakdown."

"Although high electric fields have been used in DC and RF applications for many years, up to now there has been no fundamental agreement on the cause of breakdown in these systems … Until our work, no theoretical understanding of this process developed over the last 100 years, although many papers have been written."

"Another interesting feature of this [electrical breakdown] mechanism is that the power densities involved are enormous. The numbers can be obtained from the values we measured for field emitted currents, electric field, the emitter dimensions, and volume for transferring electromagnetic field energy into electron kinetic energy. Combining these gives, $(10\ GV/m)(10^{-7}\ m)(1\ mA)/(10^{-7}m)^3 = 10^{21}\ W/m^3$, a value that seems to be greater than all other natural effects, except perhaps Gamma Ray Bursters (GRB's). The power density is comparable to nuclear weapons. Michelson and Millikan noticed the 'hot sparks' in 1905, bought a vacuum pump, (which they didn't have), and invented vacuum ultraviolet spectroscopy. Both moved on, and did not look in detail at the mechanisms involved."

Seidman, D., and Norem, J., "Experimental study of high field limits of RF cavities"

<u>Again, please refer to source URL</u>:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

In the following Slide, we modify a chart shown in Seidman & Norem's above-noted proposal to illustrate the very approximate regions of physical parameter space in which LENRs may occur if ALL the necessary preconditions that we have previously outlined are obtained. Please note carefully that just the presence of very high local E-M fields <u>by itself</u> does not guarantee that LENRs will take place at a given location in time and space

Also please note that once the nuclear processes begin, power densities in LENR-active 'patches' can go even higher for brief periods of time until nearby nanostructures are destroyed by violent 'flash' heating and LENRs temporarily cease in a given 'patch' (all of this occurs on the order of <1 to 200 nanoseconds)

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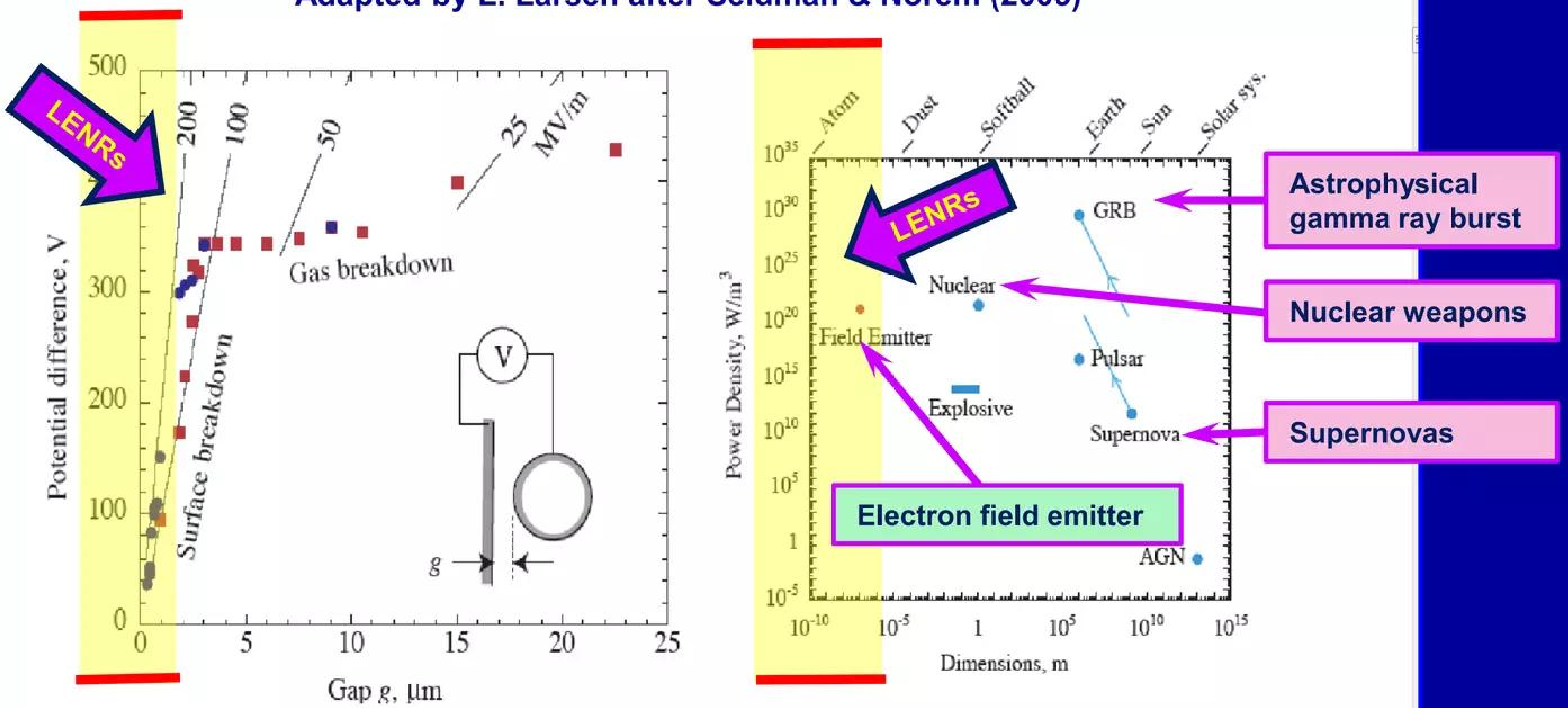
Cathodic arc discharges and LENRs are very energetic

Seidman: *"… highest power density commonly found in Nature"*

Local micron-scale power densities can be enormous during brief 'lifetime' of an LENR-active 'patch'

They can *exceed* huge power densities reached during electrical breakdown *a la* Seidman & Norem

Adapted by L. Larsen after Seidman & Norem (2005)



Lattice modification of original chart: yellow-shaded regions 'capped' by red-colored bars are approx. regions of parameter space where LENRs may occur in condensed matter systems IF all of the necessary conditions met (please refer back to earlier Slides)

Source: Fig. 2, pp. #3, Seidman & Norem 2005 proposal, *"Experimental study of high field limits of RF cavities"*

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Cathodic arc discharges and LENRs are very energetic

Seidman: *"… highest power density commonly found in Nature"*

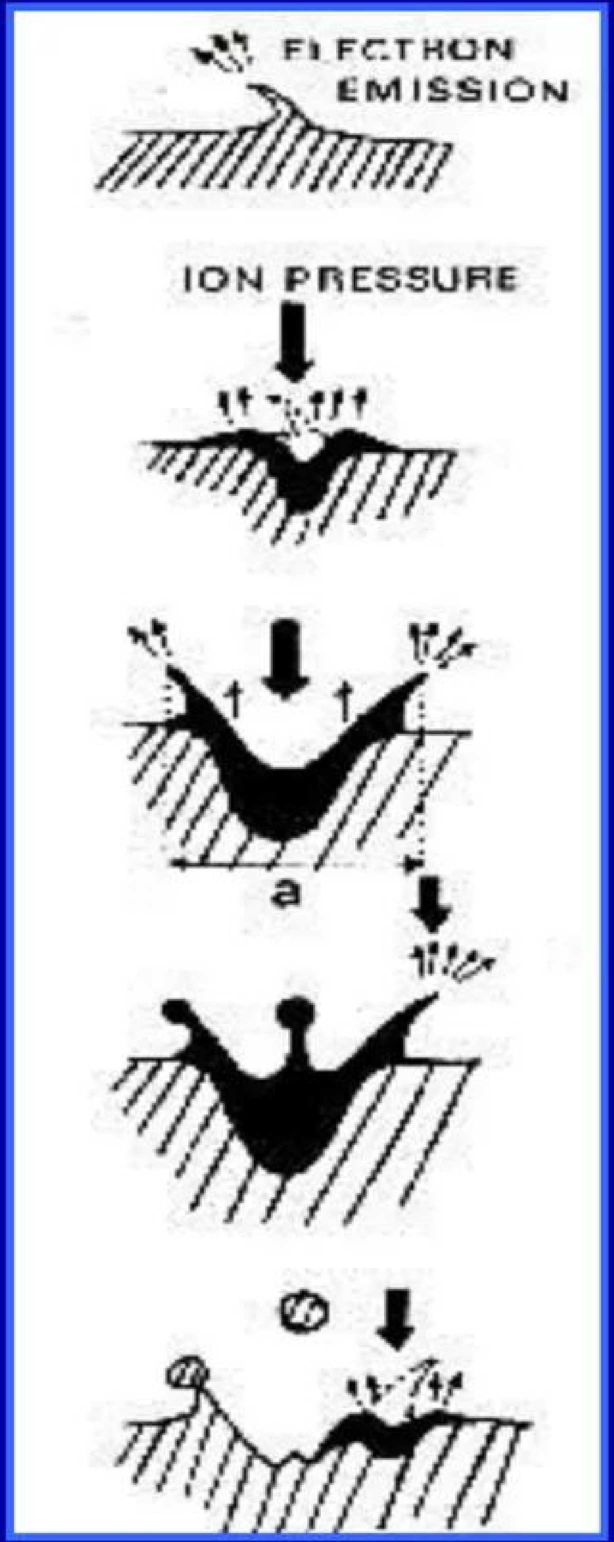
D. Seidman's comments *circa* 2005 (continued):

"We think we have developed a model of breakdown that explains the phenomenon in almost all environments ….The model strongly argues that breakdown events are the result of fragments or clusters breaking off of the surface and rapidly being ionized in the electron beams from the field emitter. Within the active volume, the power involved in these beams is comparable to nuclear weapons. This model is also generally in agreement with the experience with APFIM samples at the high fields used. Tiny APFIM samples operate at fields about 5 times higher than the local E field limit we postulate, but they also frequently fail, however there has been no systematic study of these failure modes."

"Combining these two ideas, however, one can conclude that: 1) this mechanism produces perhaps the highest power density commonly found in nature, and, 2) it is accessible to anyone with a wall switch or an electric light, and is used many times a day by everyone."

"While there has been extensive study of the time development of breakdown events from the first small local ionization to complete breakdown of a cavity, the trigger for breakdown, and how it was related to the metallurgy of surfaces has received very little attention until now. Our model predicts that the production of clusters and fragments is an essential component of breakdown. This is consistent with experience in Atom Probe Tomography, however there is almost no systematic data on sample failures under the high field environment used in data taking. Our previous work has been published in three refereed papers and many conference papers."

Note creation of ~spherical droplets



Breakdown of surface
Figure courtesy of B. Jüttner, Berlin

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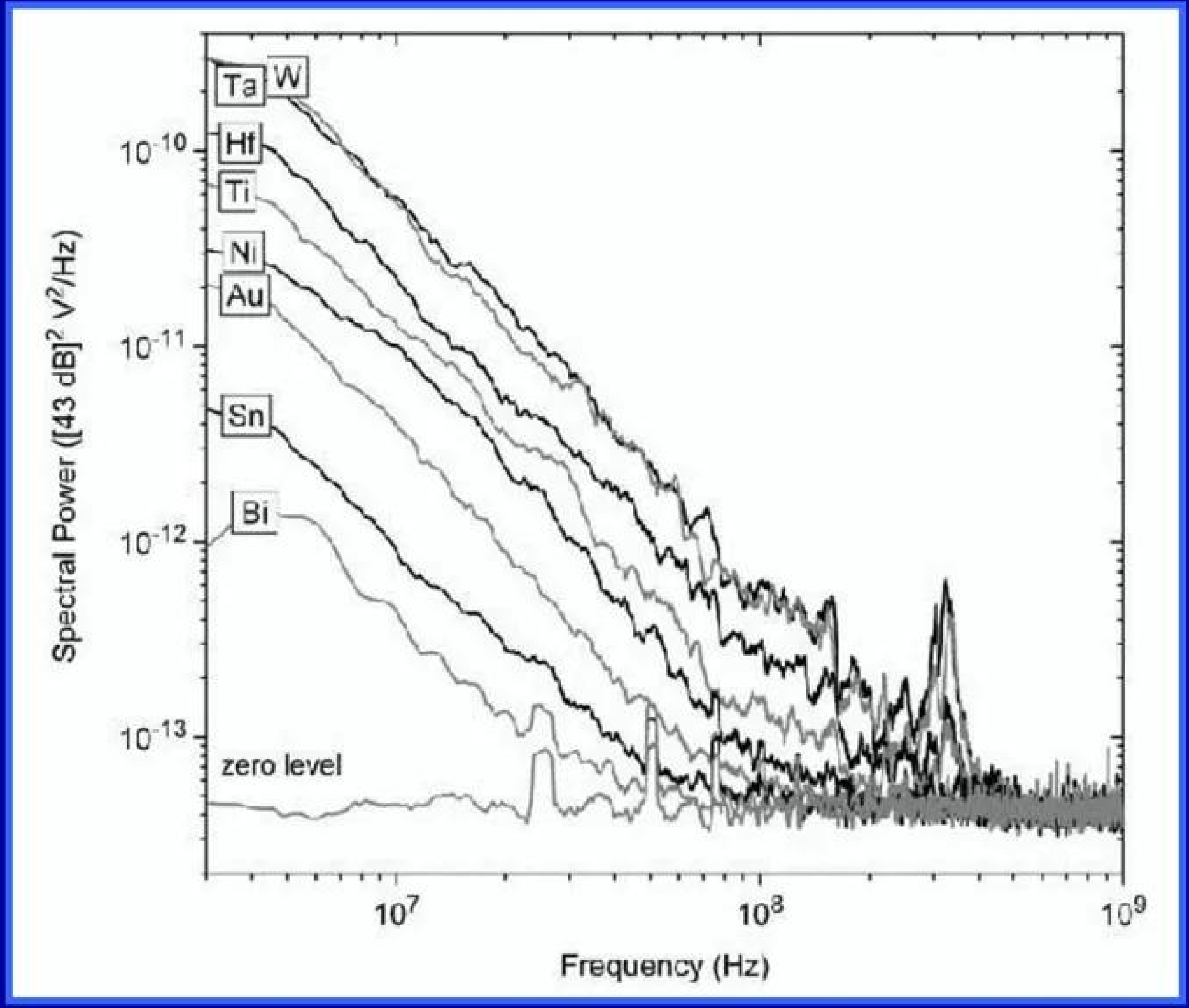
Cathodic arc discharges and LENRs are very energetic

Anders has developed model for "arc spot ignition" runaways

In 2010, Dr. Andre Anders of Lawrence Berkeley National Laboratory (LBNL) publicly posted a very interesting 32-slide PowerPoint presentation titled "*Cathodic Arcs, and related phenomena*":

- ✓ **Among other things, he believes that 'hot cathode spots' are fractal, as shown in the Figure to the right, and that the electron current is higher than the arc current (his Slide #6)**
- ✓ **On his Slide #7, he makes an important distinction between *collective* electron emissions that occur in arc discharge regimes (namely, thermionic, field, thermo-field, and explosive emissions) versus "*individual*" electron emission mechanisms (such as secondary electron emission by primary ion, electron, or excited atom impact, and photo-emission) that tend to occur in glow discharge regimes**
- ✓ **On Slide #11, he describes an "*arc spot ignition*" involving a, "*Local thermal run-away process [that] leads to micro-explosion and formation of extremely dense plasma*"**

Evidence that "cathode spots" are fractal:



Original source: A. Anders, "*Cathodic Arcs*," Springer, NY (2008)

In 2010, this Figure appears in a workshop presentation:

A. Anders (Lawrence Berkeley National Laboratory - LBNL), "Cathodic Arcs, and related phenomena," work supported by the U.S. Department of Energy under Contract DE-AC02-05CH11231

URL =

https://twindico.hep.anl.gov/indico/getFile.py/access?sessionId=3&resId=0&materialId=1&confId=69

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Cathodic arc discharges and LENRs are very energetic

Anders' model for "arc spot ignition" runaways can lead to LENRs

Dr. Andre Anders - LBNL (continued):

On Slide #11, he then elaborates his model as follows:

High [local] electric field, enhanced by:

- **Protrusion (e.g. roughness, previous arcing)**
- **Charged dielectrics (e.g. dust particles, flakes)**

Feedback Loop

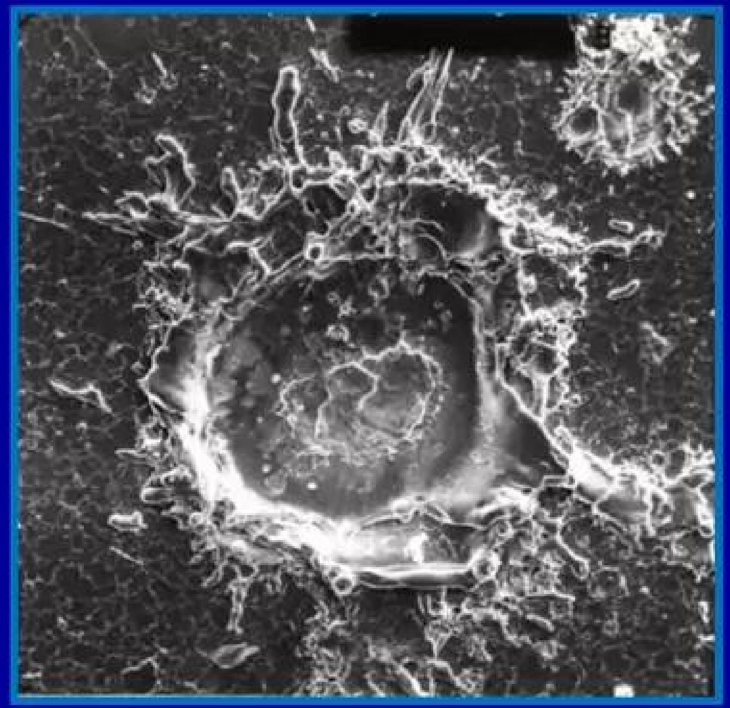
1. **Higher field leads to locally greater e-emission**
2. **Joule heat enhances temperature of emission site**
3. **Higher temperature amplifies e-emission non-linearly**
4. **Runaway!**

To which we would like to add, based on W-L theory:

5. **LENRs --- if other necessary preconditions are also fulfilled, as we have outlined elsewhere**

Anders then goes on to show an array of fascinating SEM images of surfaces on which 'explosive' cathode arcs have occurred that bear a certain resemblance to post-experiment SEM images of LENR cathodes (with a difference in aspect-ratios that we will explain)

"Crater" in cathodic arc experiment:



A. Anders: "*Cathodic Arcs, and related phenomena*," Slide #12 of 32 (2010)

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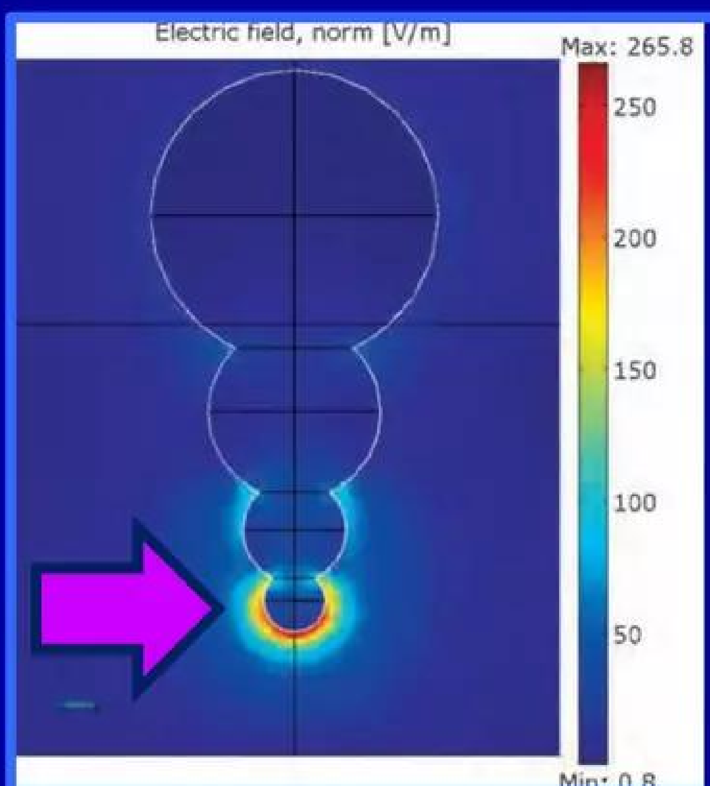
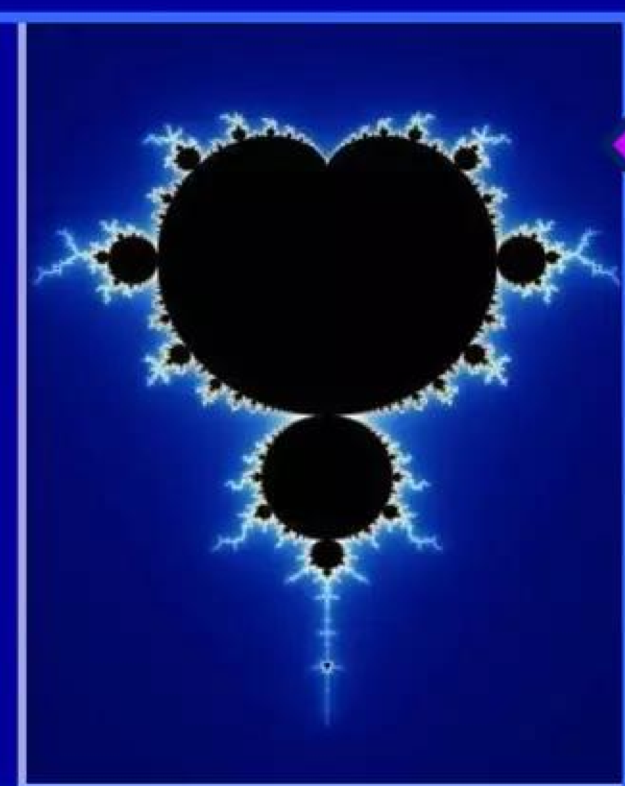
Arcs and LENRS both involve very high local E-M fields

E-fields can increase greatly between nanoparticles and at sharp tips

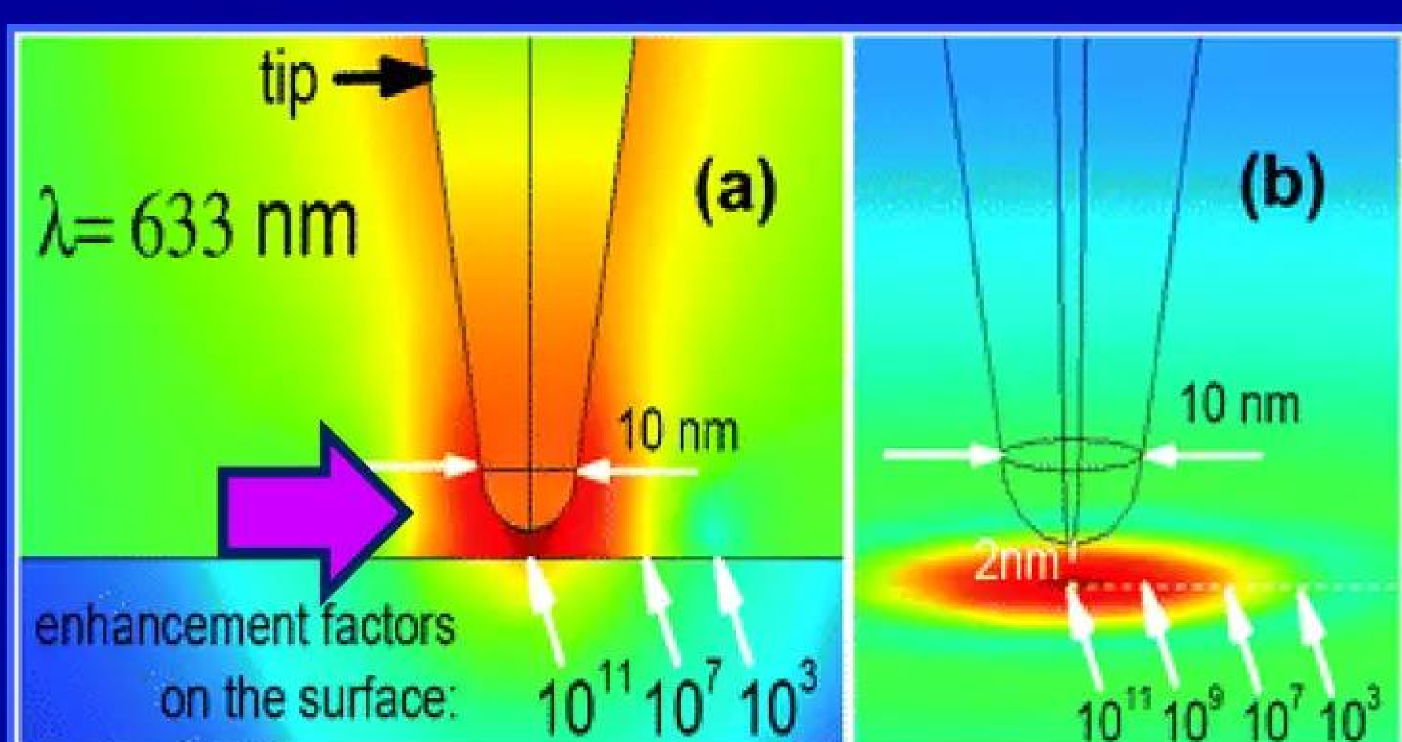




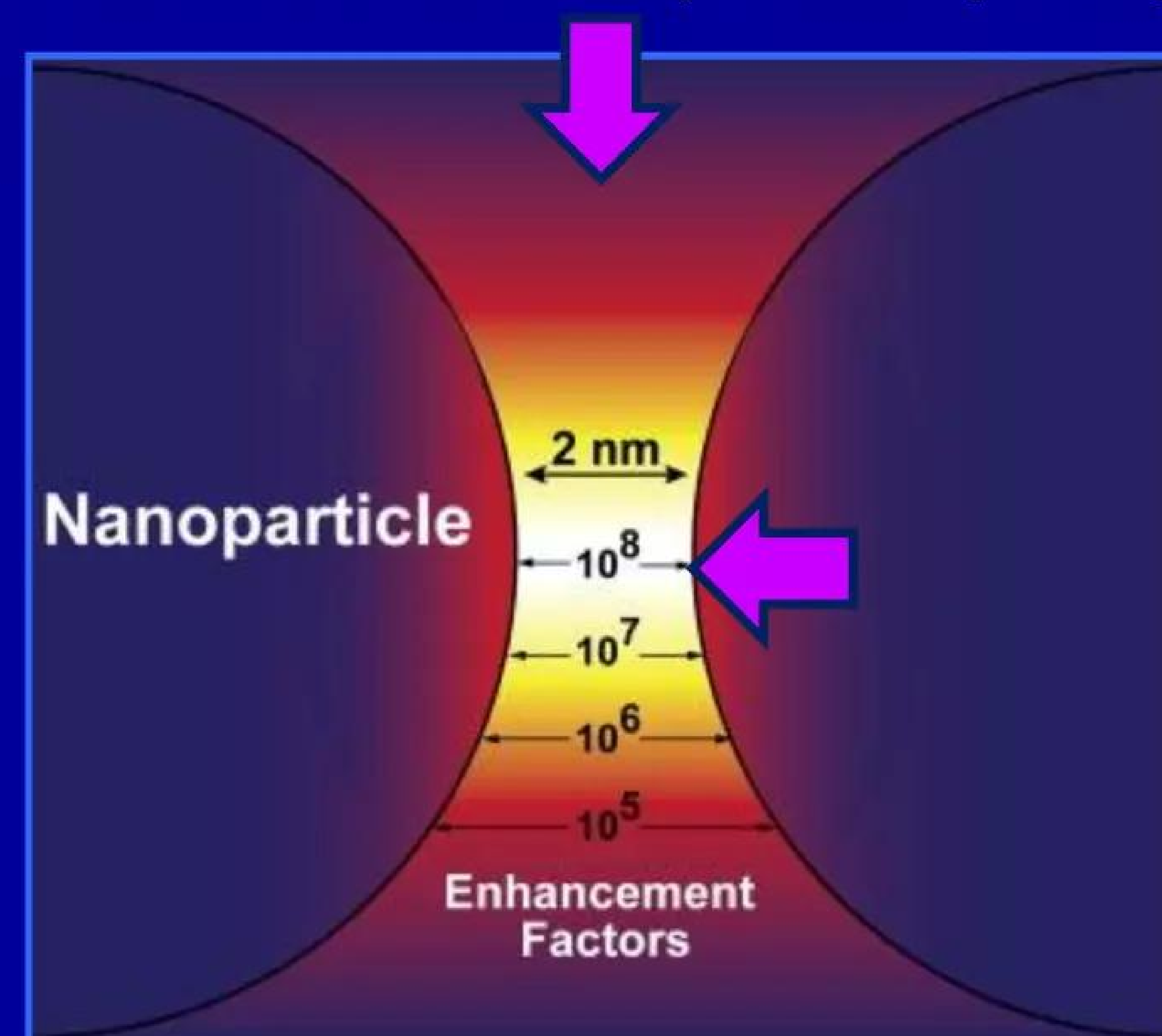
Sharp tips can exhibit the so-called "lightning rod effect" in terms of local enhancement of electric field strengths

Electric field enhancement at nano-antenna tip: R. Kappeler *et al.* (2007)

Above: classic Mandelbrot fractal form



E-M field strength enhancement as a function of interparticle spacing



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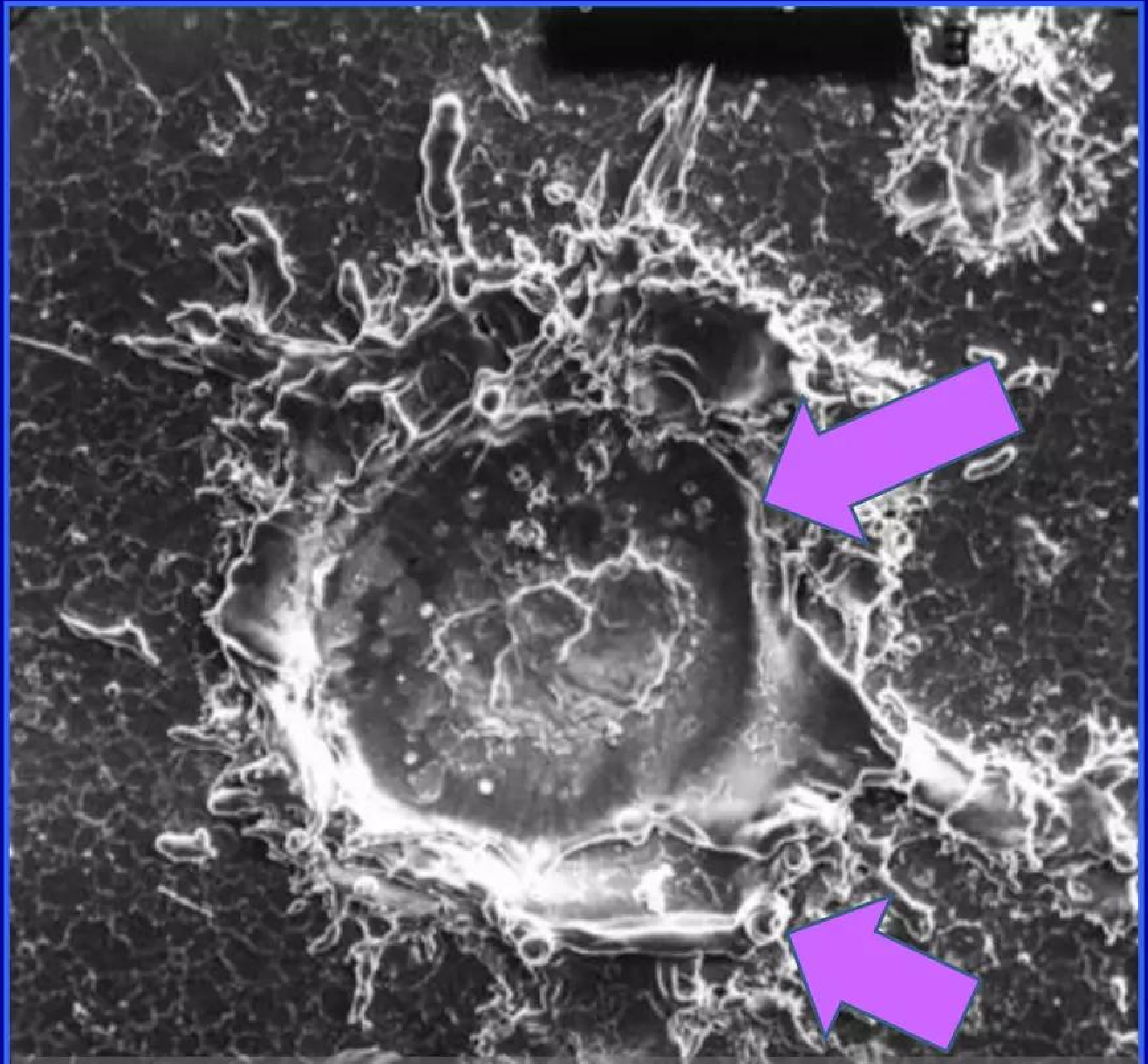
Morphological similarities between arc ‘craters’ and LENRS

Key difference: LENR ‘craters’ can have much higher aspect-ratios

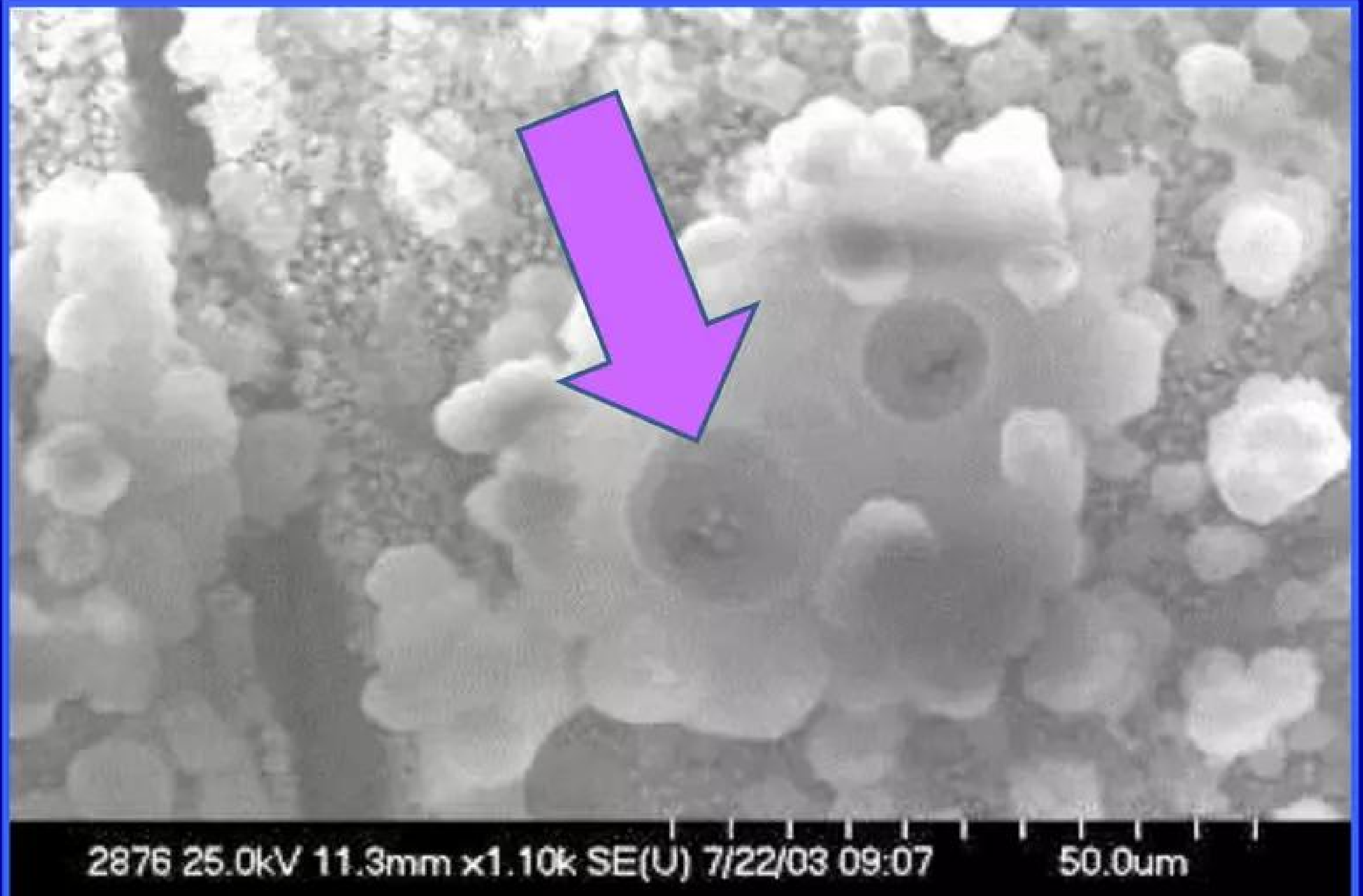
Anders’ SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

Cathodic arcs



Anders cathodic arc: post-experiment surface feature

LENRs



LENR Pd surface post-experiment: P. Boss et al.

Please note what appears to be a somewhat common morphological difference between LENR ‘craters’ and those produced by prosaic cathodic arcs as discussed by Anders. Many central ‘craters’ in LENR SEM images often appear to have more sharply defined, ‘crisper’ interior walls and greater depths (relative to the surface area) compared to arc discharges without LENRs (i.e., a higher aspect-ratio); this may be indicative of much more rapid, higher levels of heating than those envisioned by Anders

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This example of laser ablation ‘crater’ has high aspect-ratio

‘Craters’ at many LENR-active sites often have high aspect-ratios

Fig. 6 from Karnakis *et al.* (2009)

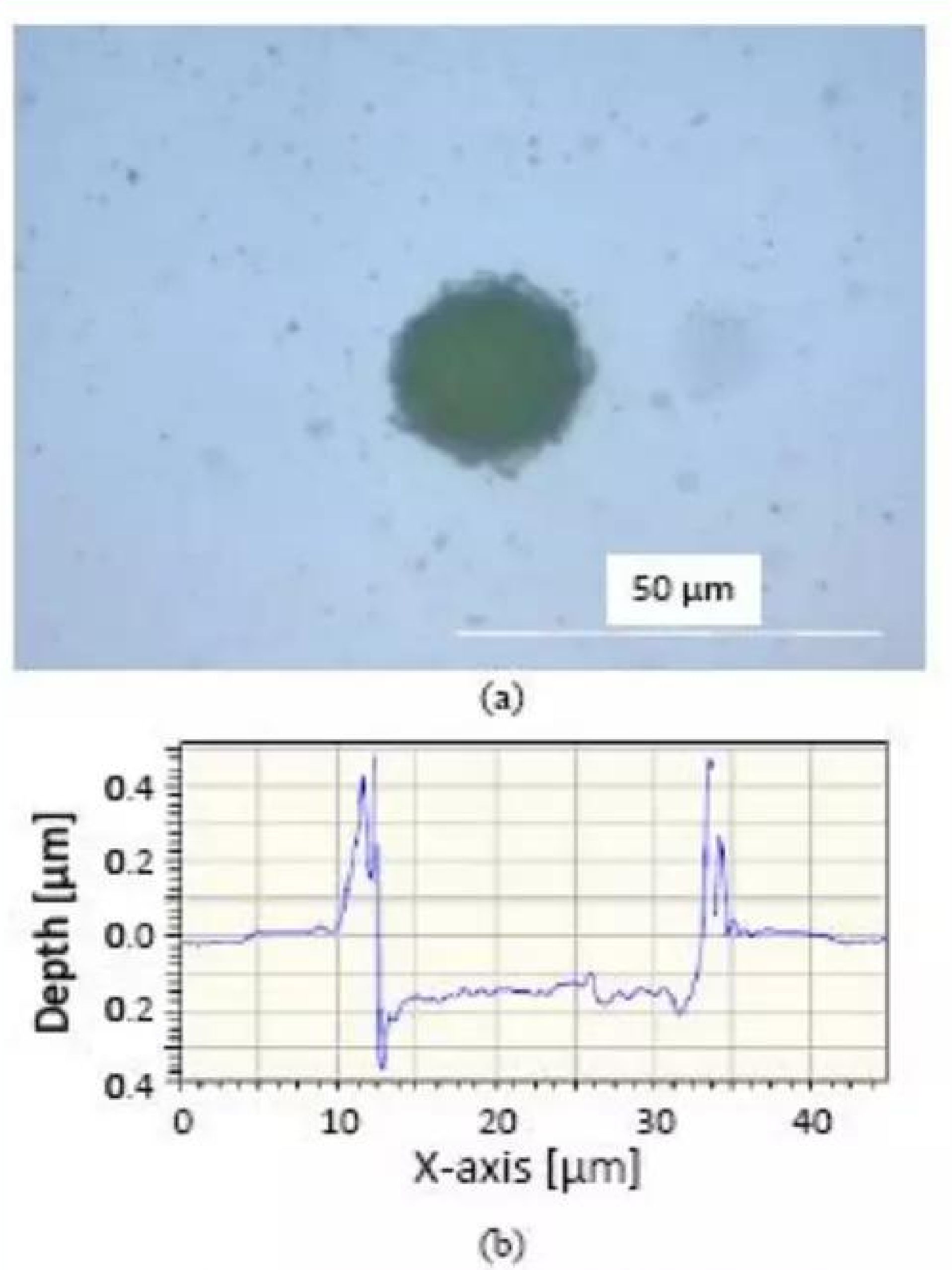


Fig. 6 (a) Optical microscope image of ps laser ablated cathode crater on LEP. Single pulse ablation, 532nm, 10ps, 2.5µJ; Bar 50µm, (b) Depth profile of the ablated crater, depth~140nm. Scale (X):2.5µm/div, (Y):25nm/div.

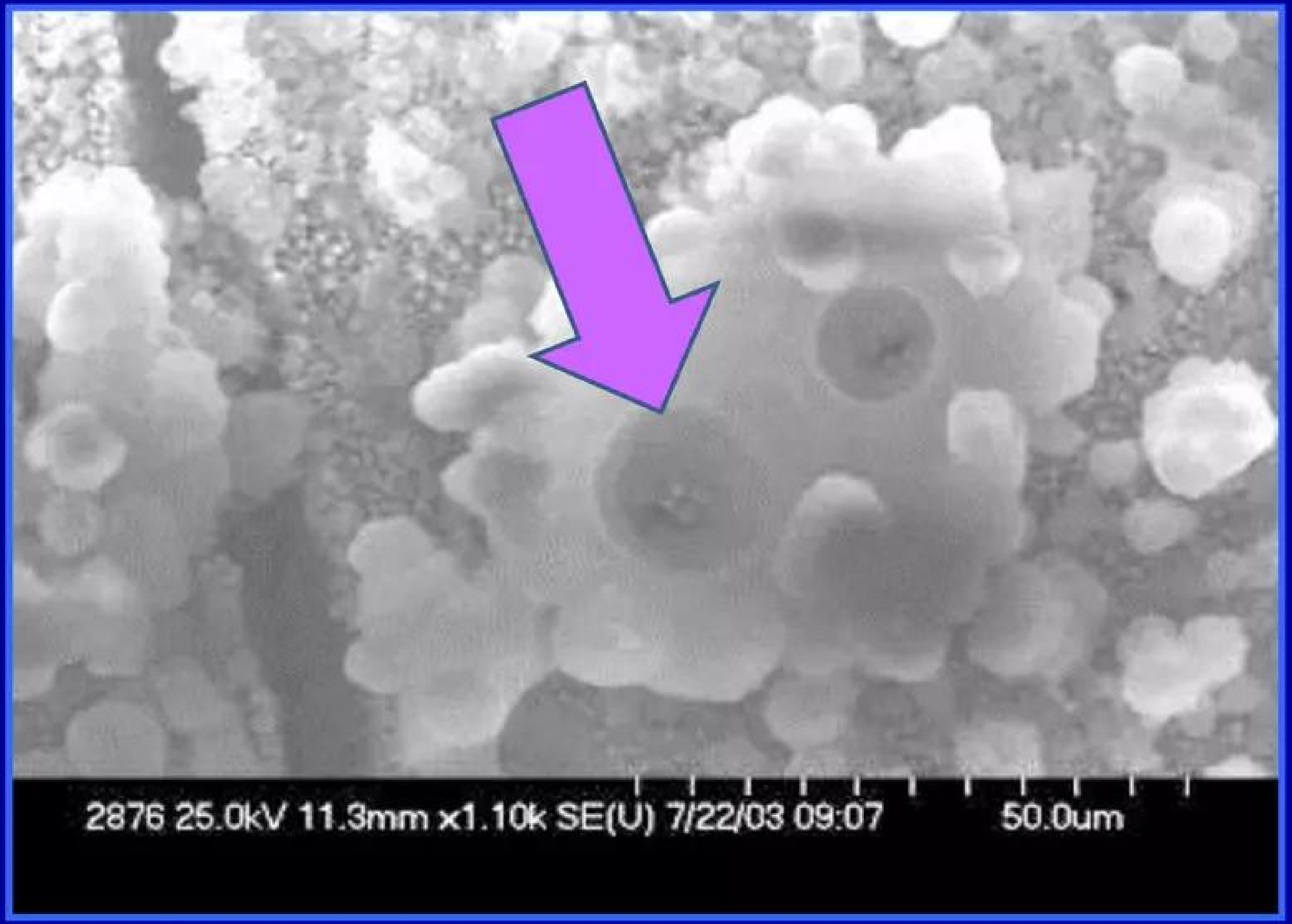
Quoting from Karnakis *et al.*:

“Laser irradiation at fluences between 137-360 *m*J/cm^2 removed the cathode layer only, resulting in a uniform flat floor and an intact LEP surface, allowing a relatively wide process window for cathode removal.

A typical example of such laser patterned Ba/Al cathode layer on the OLED stack is shown in Figure 6.

The average fluence was 230 mJ/cm^2 irradiated with an estimated spot diameter at 1/e^2 of 35 *µm*.

This resulted in a crater diameter of 21.5 *µm*.”



LENR Pd surface post-experiment: P. Boss *et al.*

Excerpted and quoted directly from:

“*Ultrafast laser patterning of OLEDs on flexible substrate for solid-state* lighting”
D. Karnakis, A. Kearsley, and M. Knowles
***Journal of Laser Micro/Nanoengineering* 4 pp. 218 - 223 (2009)**
http://www.jlps.gr.jp/jlmn/upload/25e2c628adb23db70b26356271d20180.pdf

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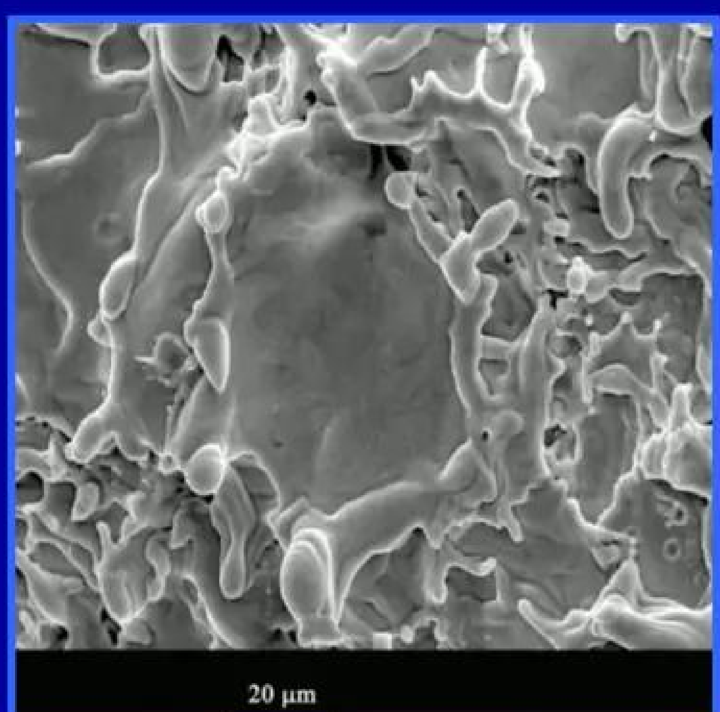
Morphological similarities between arc ‘craters’ and LENRS

Note quenched droplets ‘frozen’ in mid-formation on ‘crater’ rims

<u>Anders’ SEM photos vs. selected images of post-experiment surfaces in LENR experiments</u>:

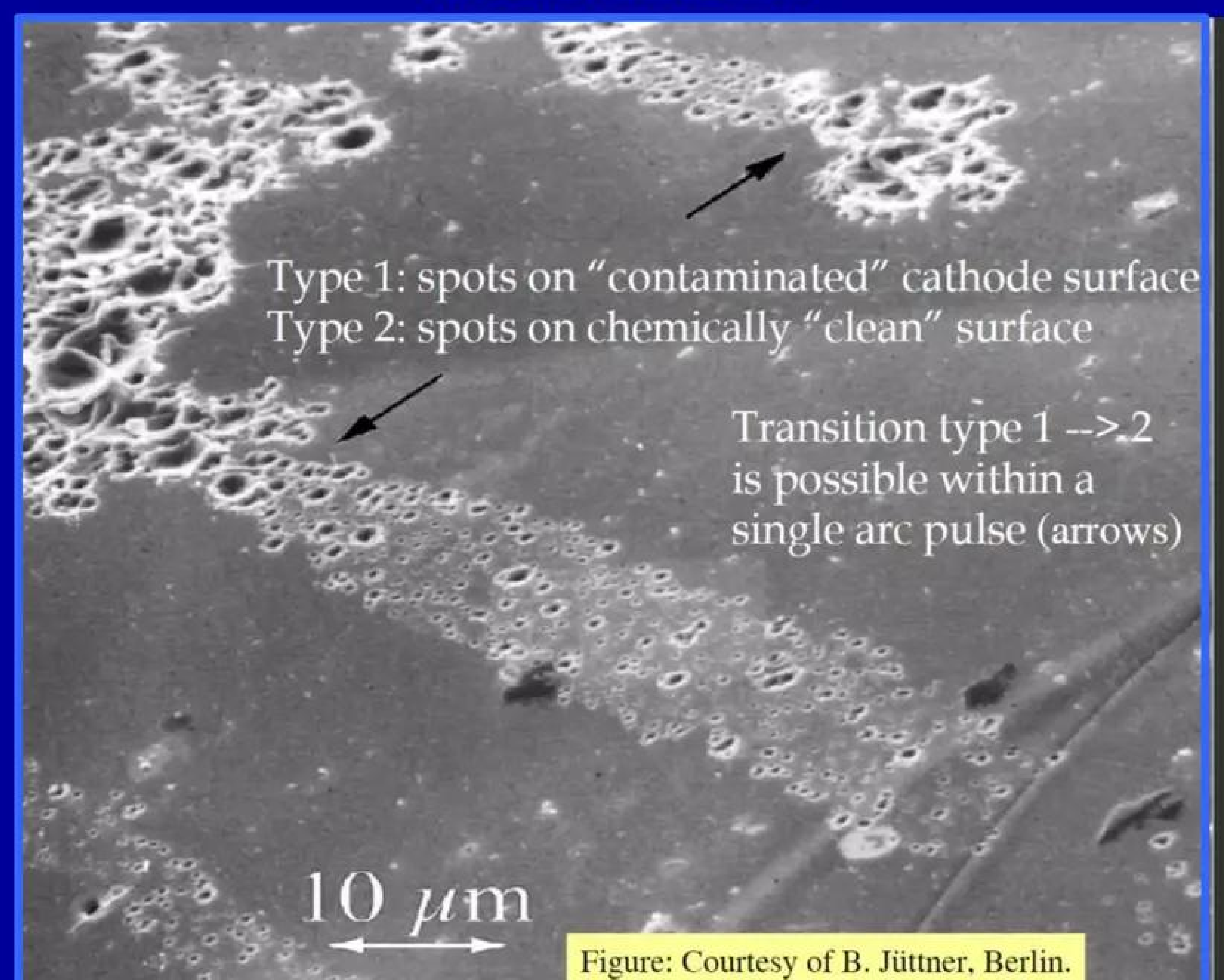
Cathodic Arcs



A. Anders “*Cathodic Arcs, an related phenomena*” (2010)

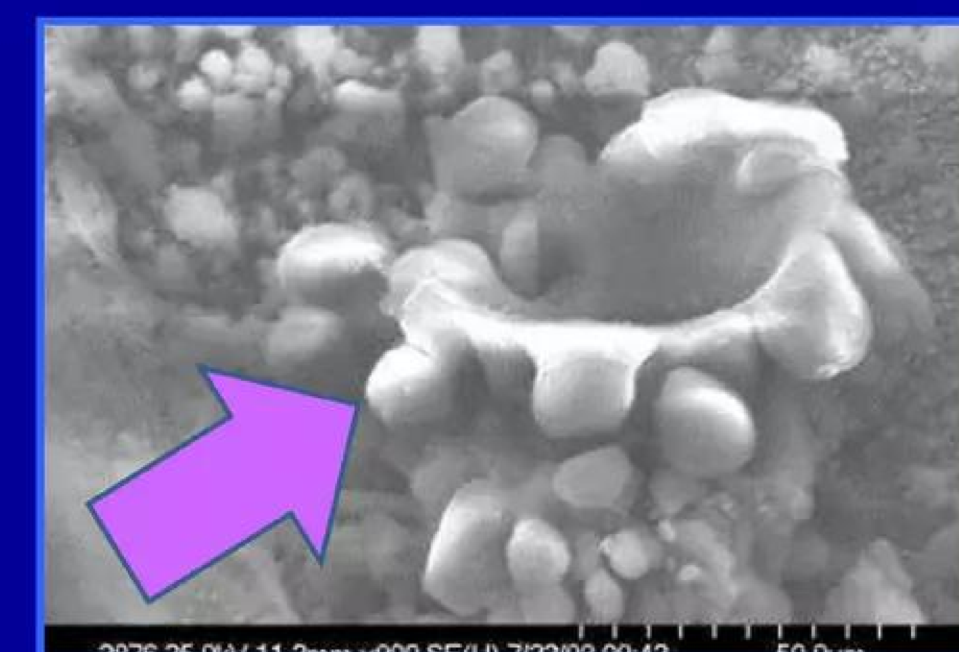
Cathodic Arcs

Anders: Slide #27

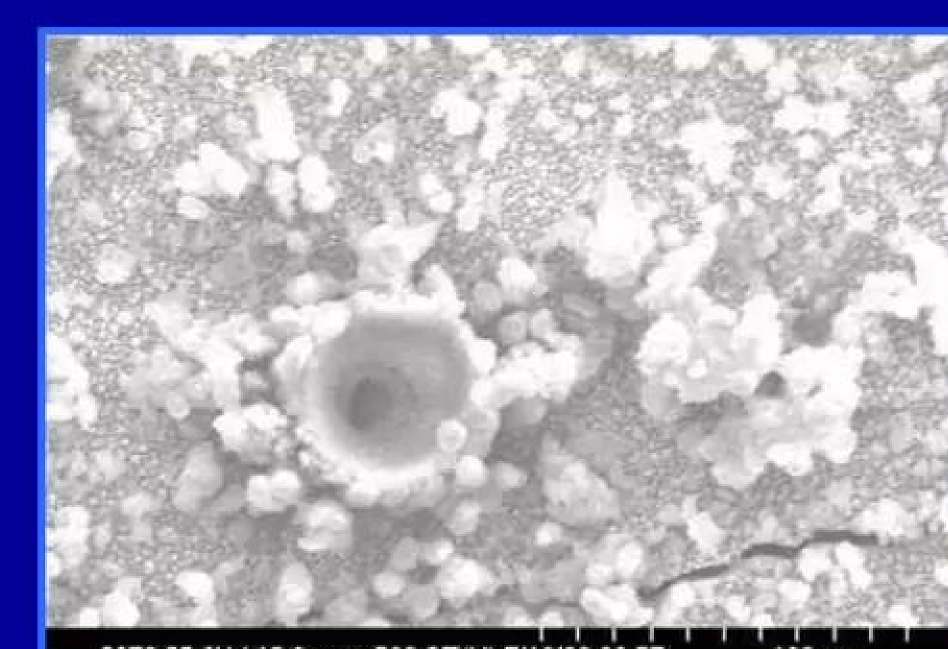


A. Anders “*Cathodic Arcs, and related phenomena*” (2010)

LENRs



P. Boss *et al.* , US Navy - SPAWAR

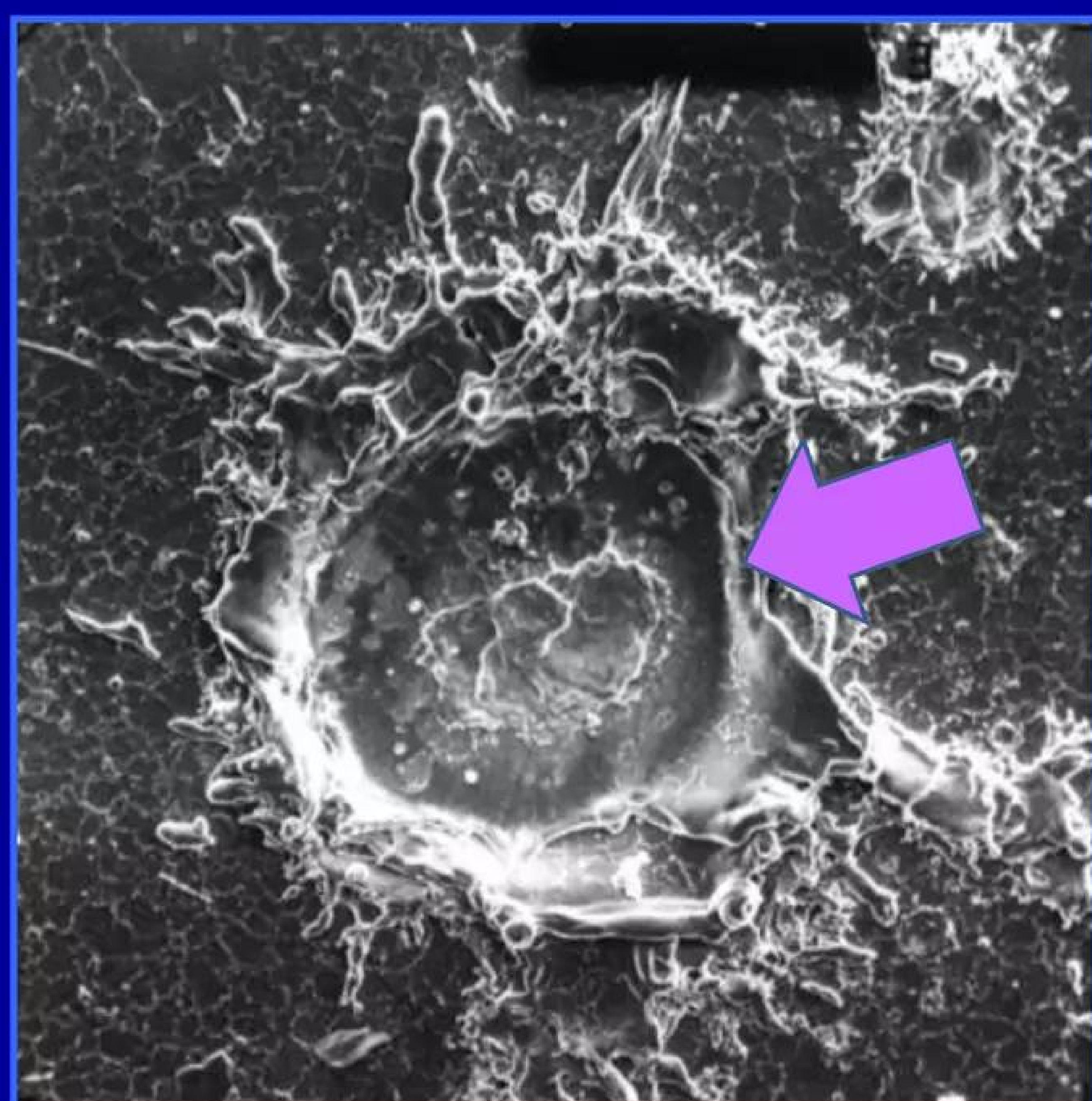


Morphological similarities between arc 'craters' and LENRS

Note much higher aspect-ratios of some LENR crater-like structures

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

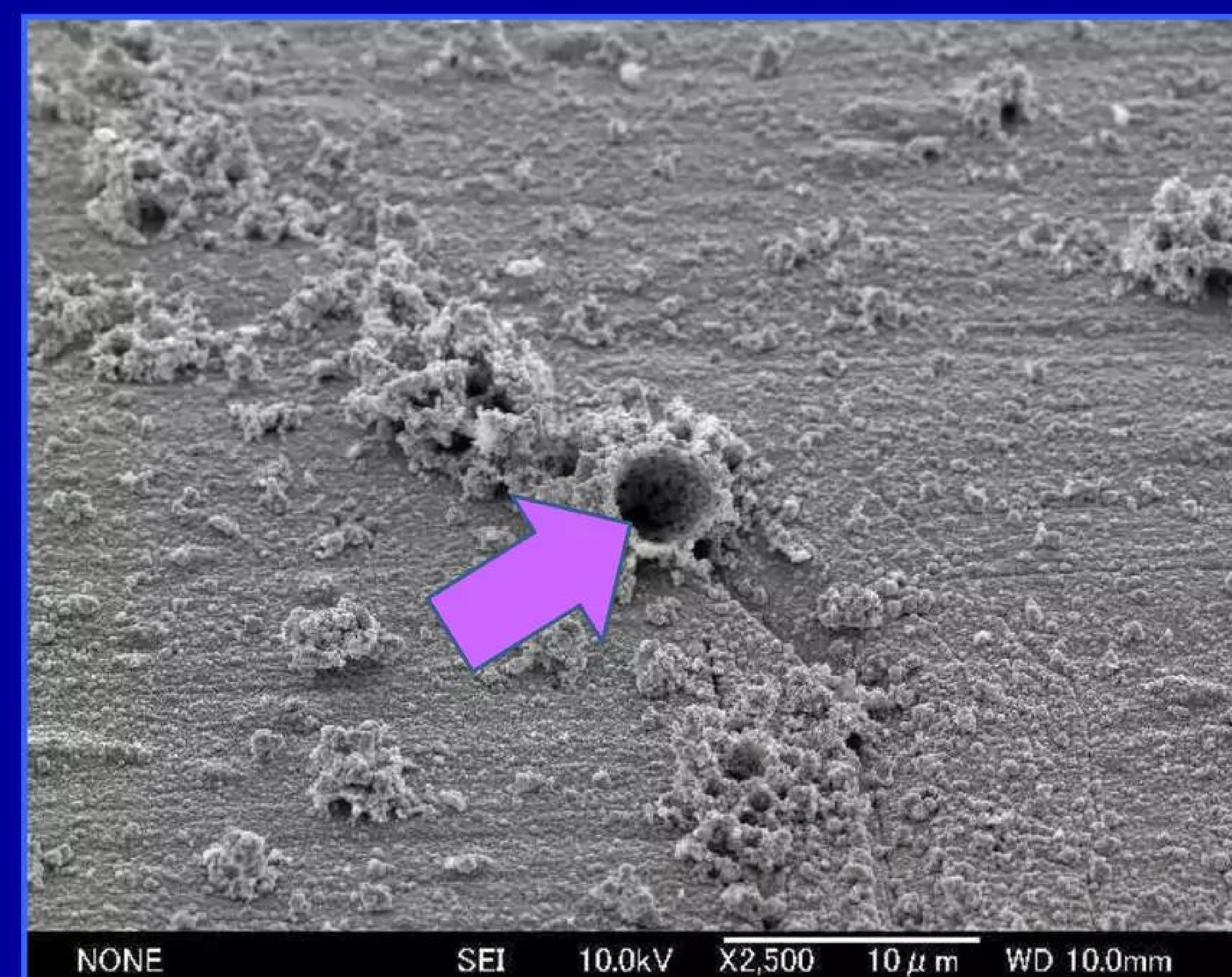
Cathodic Arcs



A. Anders: "*Cathodic Arcs, and related phenomena*," Slide #12 of 32 (2010)

LENRs

Free copy of paper: http://www.lenr-canr.org/acrobat/ToriyabeYelementala.pdf



"*Elemental analysis of palladium electrodes after Pd/Pd light water critical electrolysis*" Y. Toriabe *et al.*, Fig. 9

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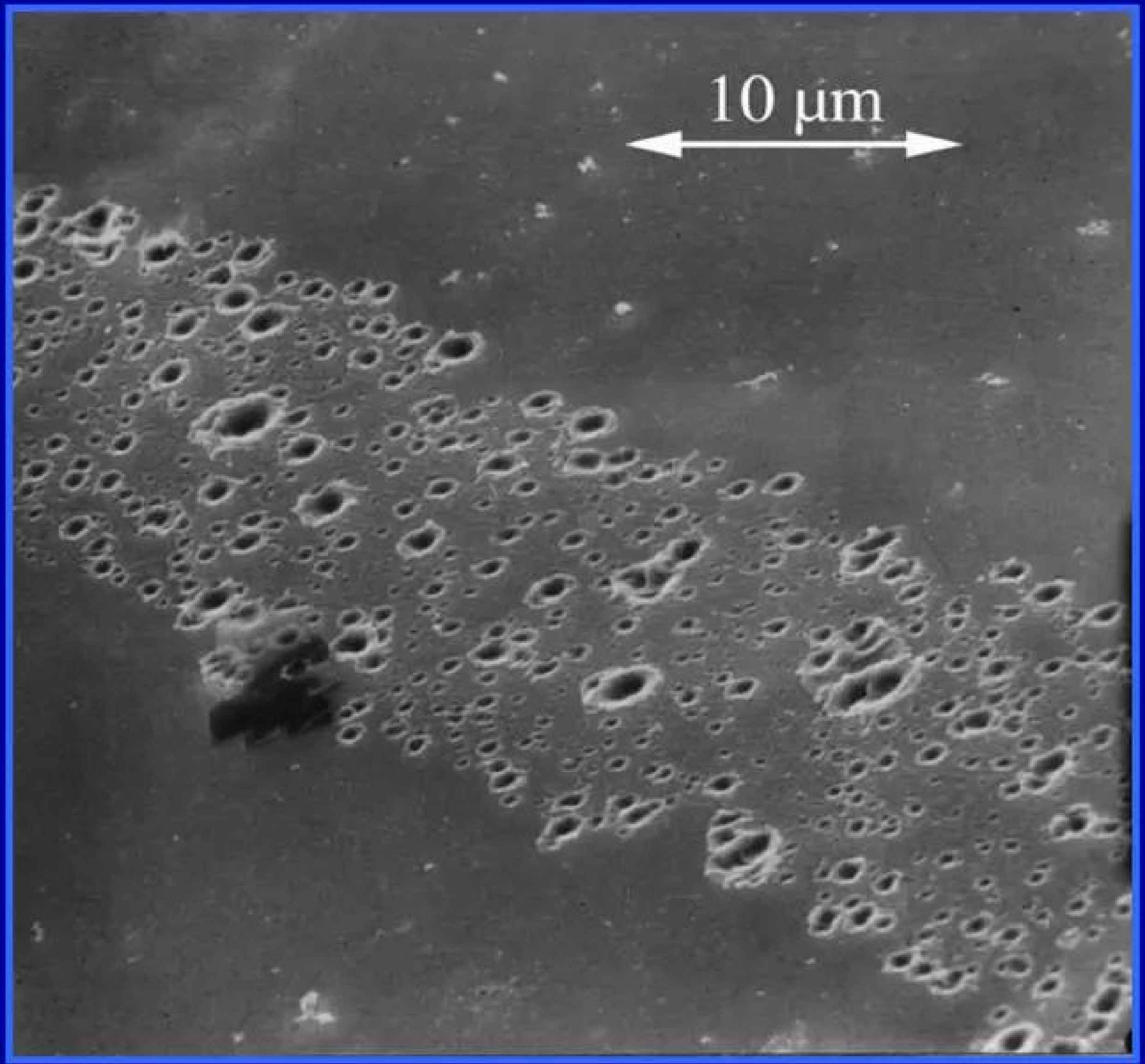
Morphological similarities between arc 'craters' and LENRS

Anomalous non-contaminant elements seen near LENR-active sites

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

Cathodic Arcs

A. Anders "Cathodic Arcs, and related phenomena" (2010)



A. Anders: Spot Type 1 - "*contaminated*" surface

LENR surface shown to right, which started-out smooth at the beginning of the experiment, appears to be much rougher in texture than the cathodic arc

Free copy of Zhang and Dash paper at:

http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

Quoting from discussion of Fig. 10: "Ni was listed as "not detected" in the chemical analysis provided by the vendor of the Pd foil. It is very unlikely to have resulted from the cold rolling process or from electrodeposition because it is highly localized near one corner of the cathode. If it is the result of either contamination from the rolling mill or from electroplating it should not be highly localized on only one corner of the cathode. It could not have resulted from SEM systems because the stainless steel components of the SEM chamber also contain Fe and Cr. Fe and/or Cr are not present in any of the spectra. The SEM does not have components made of pure Ni. Therefore, the origin of the Ni is not known."

LENRs

Zhang and Dash (2007) --- Fig. 10. SEM picture of region #2 in Fig. 4(b). SEM No.WS060424Pd-H-CC-i2-150X

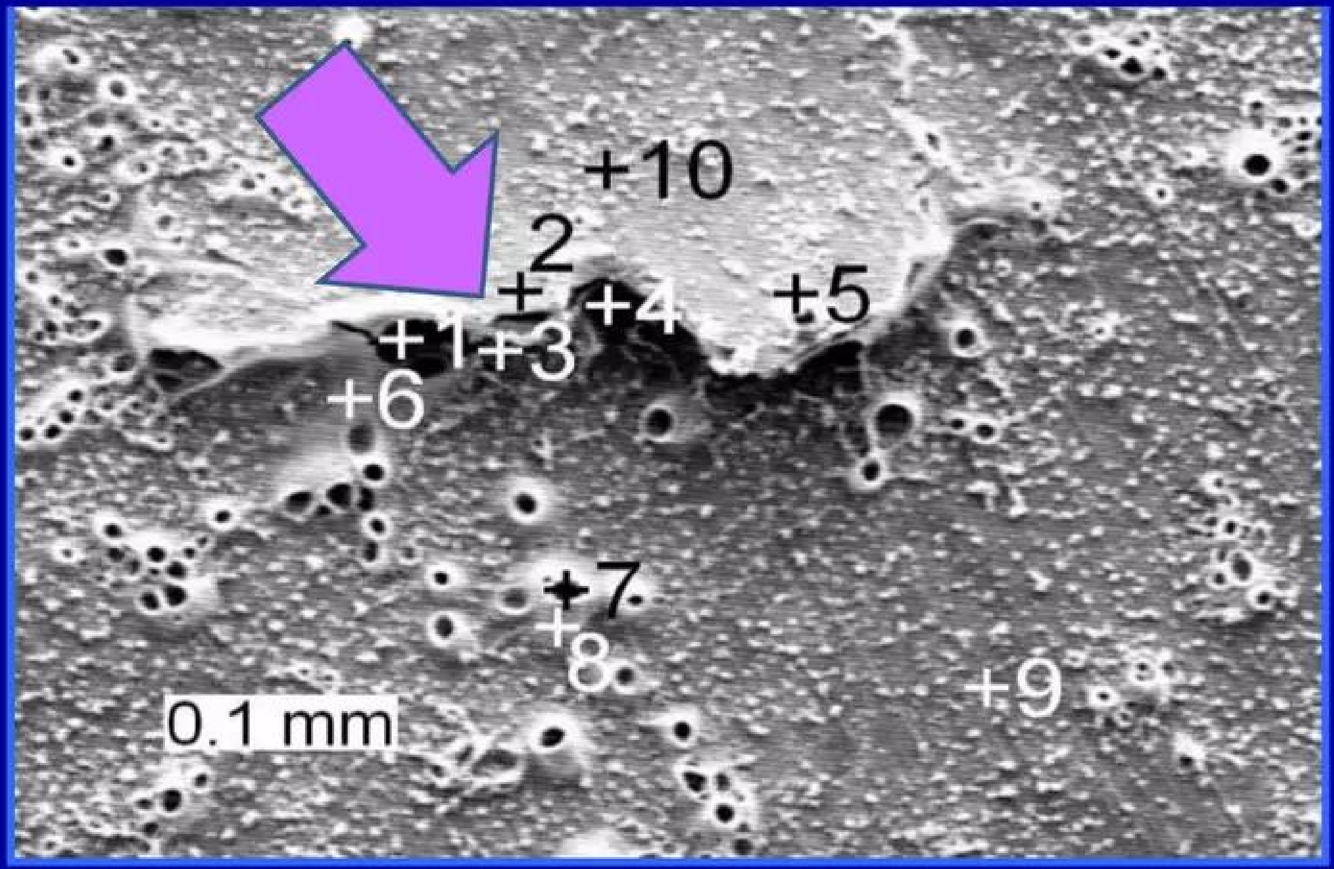
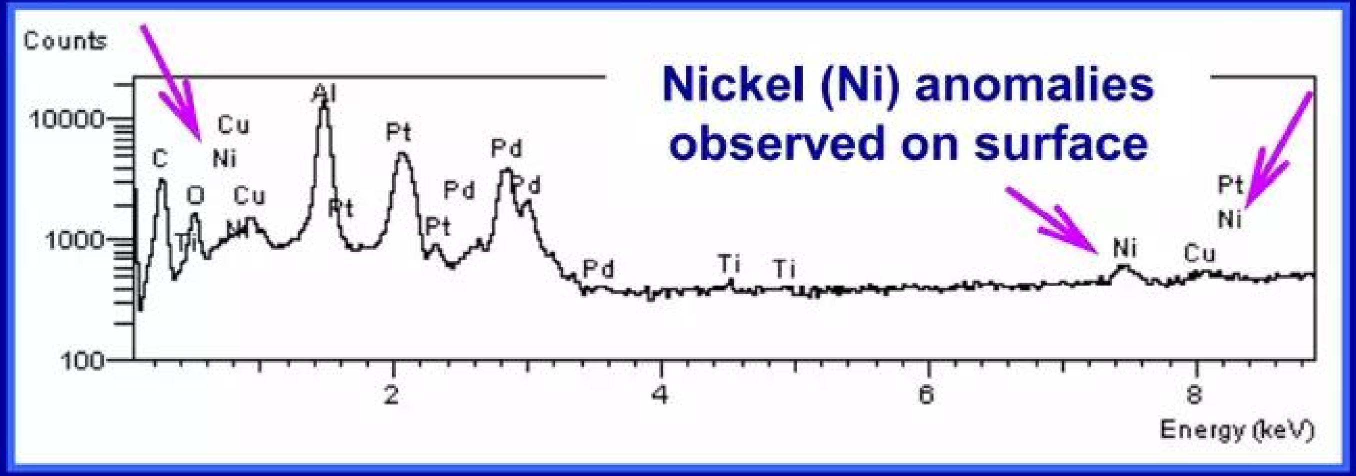


Fig. 11. Characteristic X-ray spectrum of spot #1 in Fig. 10.



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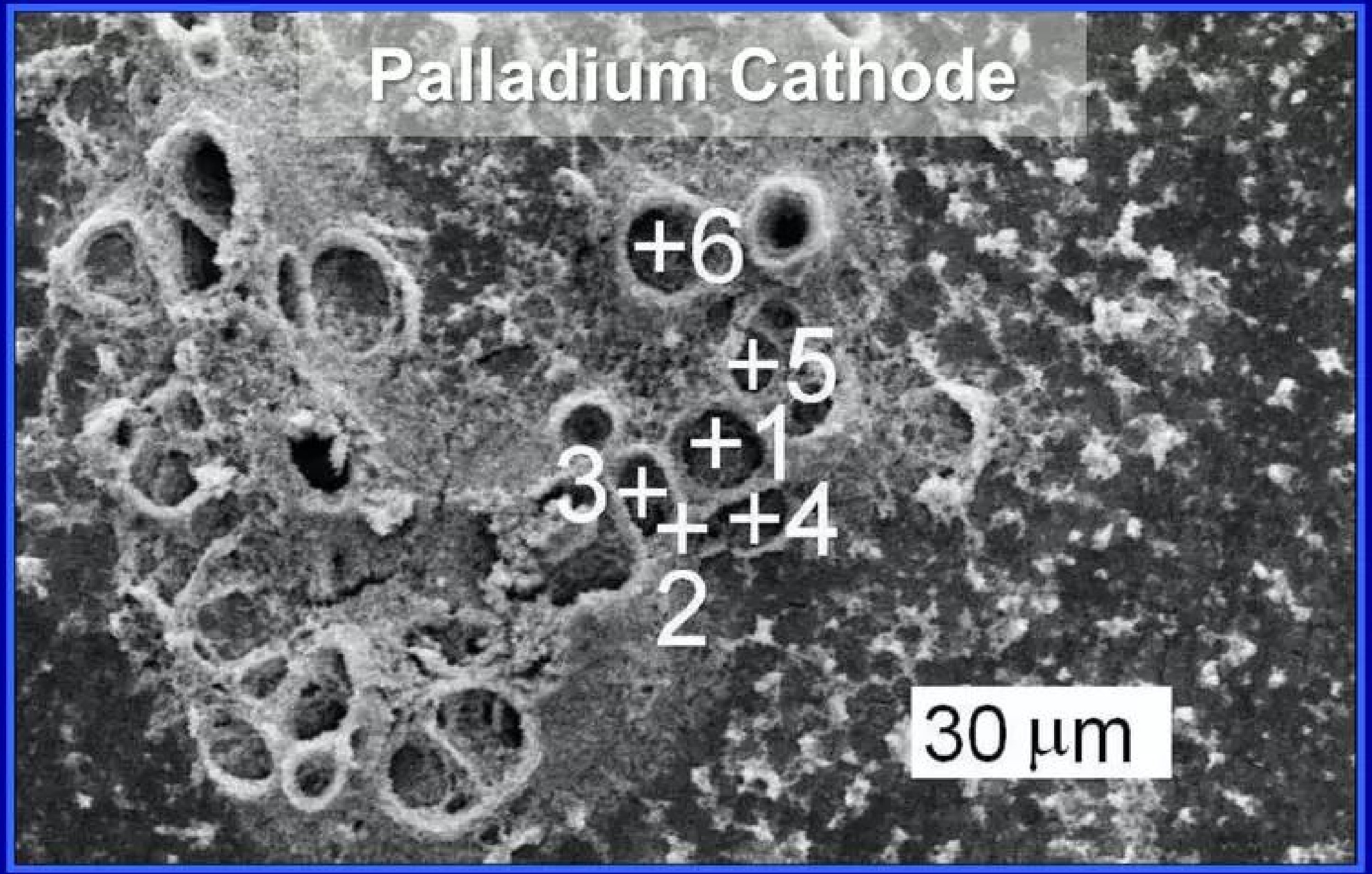
LENR transmutation products can be found near 'craters'

Number of other researchers have also observed this with SIMS

Selected images of post-experiment surfaces in LENR experiments by Zhang and Dash:

LENRs: Zhang and Dash (2007) - Fig. 8



Note: Pd surface b.p. = 2,970° C

Free copy of Zhang and Dash paper at:

http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

LENRs: Zhang and Dash (2007) - Fig. 9

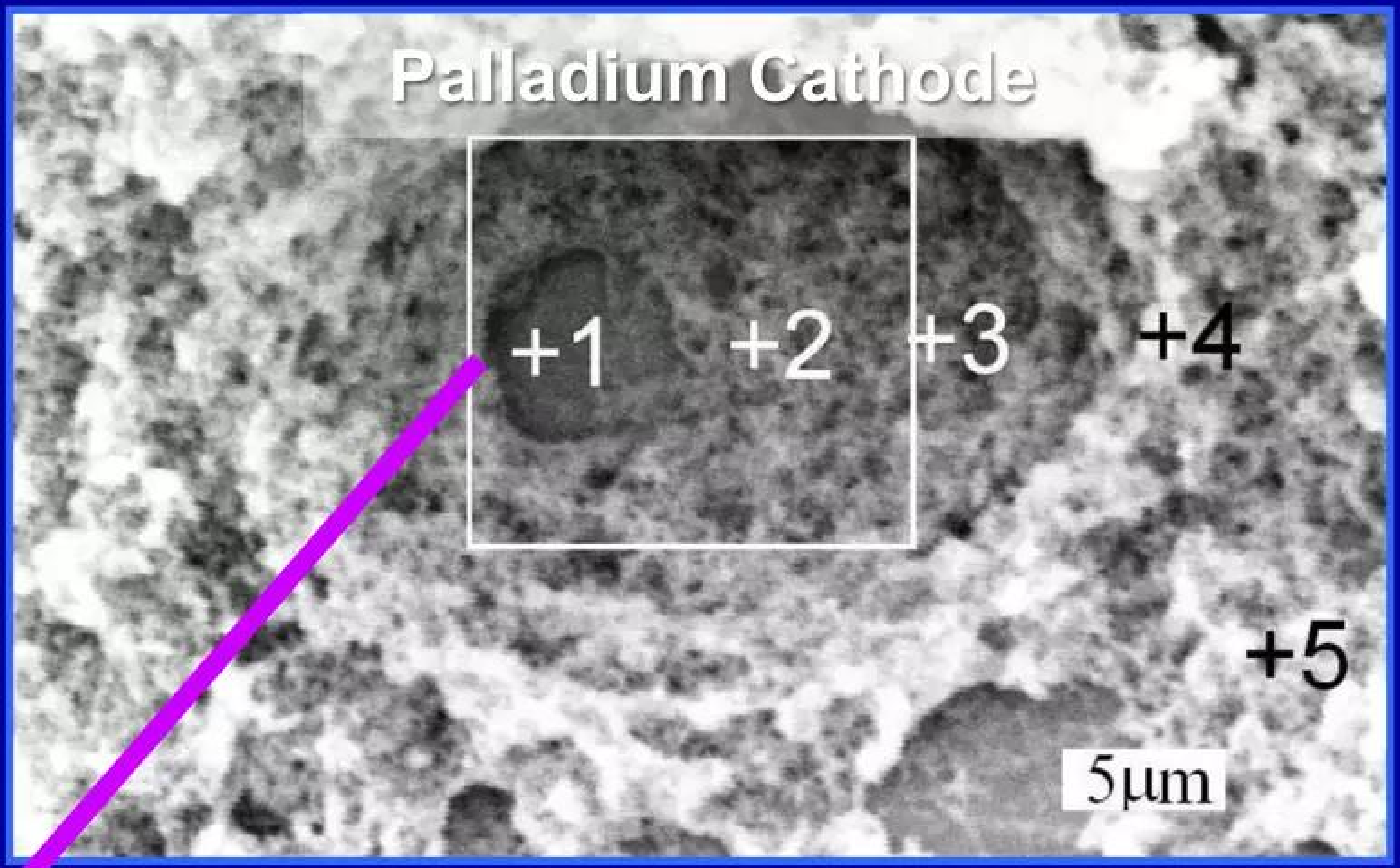


Fig. 9. SEM picture of crater at another time. SEM No.WS060607Pd-H-CC-i2-2kX

Quoting: "The most common finding is that silver occurs in craters, such as those shown in Fig. 8. These craters with rims almost certainly formed during electrolysis. Pt deposition was concentrated on these protruding rims."

Zhang and Dash: Table IX. Relative atomic percent concentrations of silver (Ag) in area and spots shown in Fig. 9

Spot #	wa*	area**	+1	+2	+3	+4	+5
Ag/(Pd+Ag)	1.2 +/- 0.5	5.6 +/- 0.4	6.8 +/- 0.4	5.6 +/- 0.3	6.3 +/- 0.4	3.6 +/- 0.6	1.2 +/- 0.5

*wa = whole entire area comprising image in Fig. 9

** area = delimited by the white square outlined in Fig. 9

Following likely took place in these experiments:

neutron capture; beta decay

Pd + *n* → unstable *n*-rich Pd isotope → Ag isotopes

With or without LENRs, arcs can trigger thermal runaways

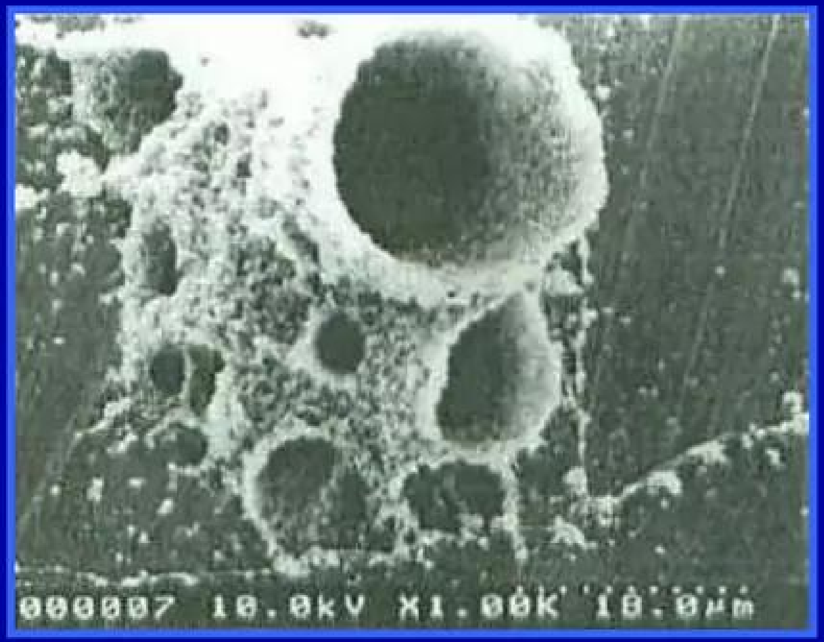
LENR-triggered runaways may be rarest but possibly deadliest type

Lattice summary comments:

- ✓ Although there are differences, there is a degree of morphological similarity in SEM images of post-experiment cathodic arc surfaces (e.g., crater-like structures and related droplets) compared to those observed after LENR-related experiments
- ✓ To the extent that such morphologies are truly indicative of very rapid heating and quenching in small areas of cathode surfaces, it implies that temperatures reached in such 'hot spots' or 'patches' are briefly high enough to melt, if not likely boil and vaporize, substrate metals, e.g., Palladium (Pd) boiling point = 2,970^{O} C or other transition metals, including refractory ones and even Tungsten
- ✓ W-L theory would suggest that, if the necessary preconditions are met, LENRs can be triggered in high-local-current arcs and related high-field electrical phenomena including field emission and surface breakdown processes
- ✓ Variety of different nuclear transmutation products observed by a large number of LENR researchers in and around surface structures such as 'craters' suggests that LENRs are probably occurring at such locations
- ✓ Micron-scale LENR-active sites that happen to be located close to a plastic battery separator (with or without a ceramic layer) will vaporize and ionize a local region of separator which can in turn trigger an internal electrical short there; similarly, an LENR 'patch' occurring on the surface of a Lithium cobalt oxide cathode or carbon anode can potentially trigger irreversible combustion of an electrode
- ✓ With or without the help of LENRs, electric arcs (internal short circuits) can trigger catastrophic thermal runaways in advanced batteries of virtually any chemistry

LENRs

Y. Toriabe *et al.*



Y. Toriabe *et al.*

Lattice Energy LLC

Another highly recommended reference paper:

"Thermo-chemical process associated with lithium cobalt oxide cathode in lithium ion batteries"
C. Doh and A. Veluchamy
Chapter 2 in book "*Lithium-ion Batteries*", Chong Rae Park, ed.
ISBN 978-953-307-058-2 open access content
Published by InTech (Shanghai, China) under CC BY-NC-SA 3.0 license
DOI: 10.5772/9116 (2010)
http://cdn.intechopen.com/pdfs/10407/InTech-Thermo_chemical_process_associated_with_lithium_cobalt_oxide_cathode_in_lithium_ion_batteries.pdf

Summary of additional causative processes for thermal runaway events in batteries:

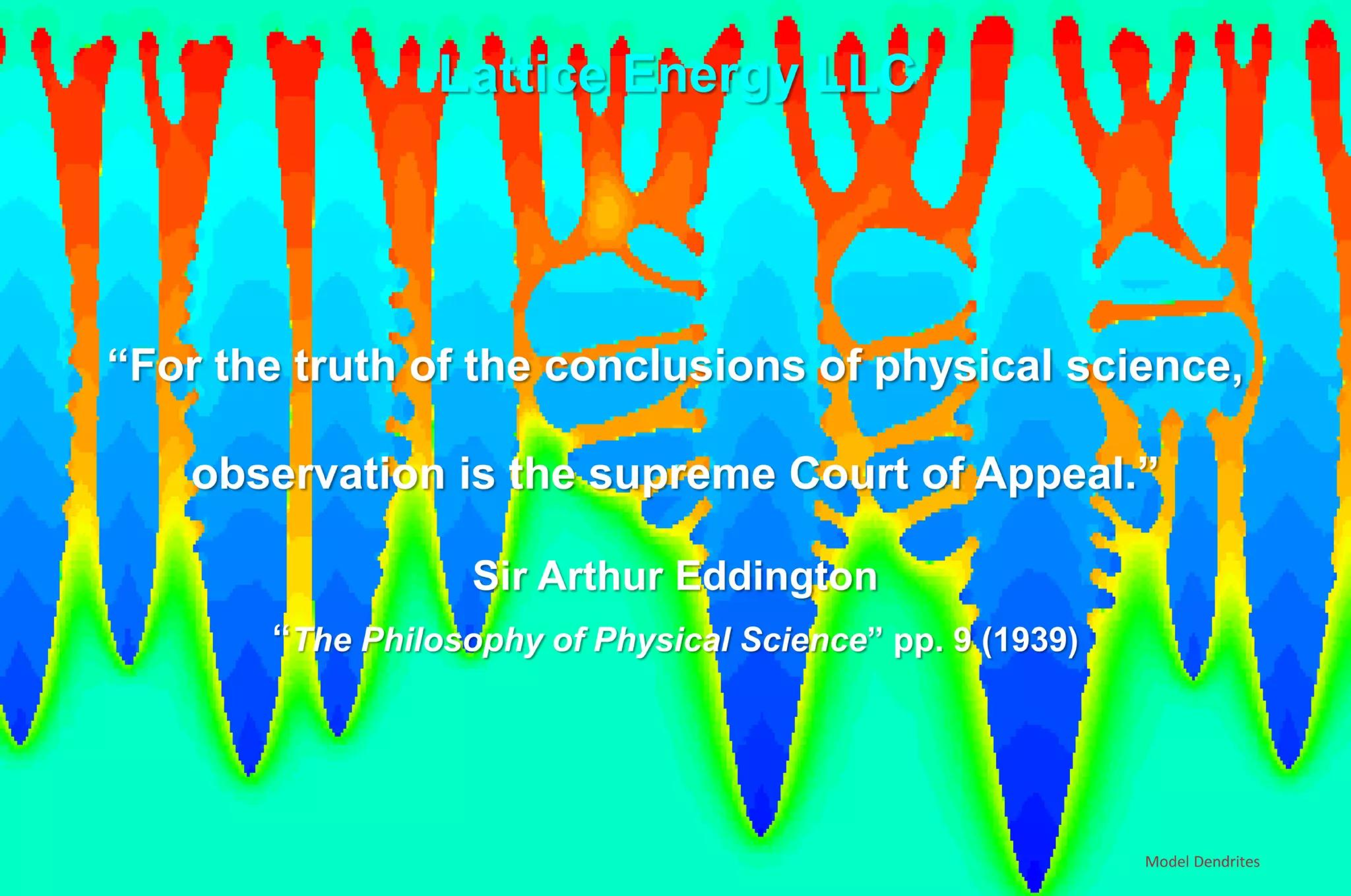
Possible causative agents that can potentially trigger battery thermal runaways	Regime or requirements	Physical dimensions	Key details	Temperature range in º C	Comments
Electric discharges: that is, arcs or sparks; alternative names for internal electrical short circuits that can occur inside battery cells	Outer 'edges' of tubular arc plasma sheath	Arc lengths can range in length from 2 *nm* between metallic nanoparticles all the way up to as long as several centimeters (*cm*) between larger structures	Chemical and nuclear reactions can occur within; dep. on current	~2,727 up to ~4,727	Heat radiation is mainly created via Joule heating by electrons and ions found in arc discharge plasma; very damaging to materials; can even breach battery cell case
	Innermost core of arc plasma's tubular sheath-like structure			~9,726 up to ~19,726	
LENR-active 'hotspots': can occur on metallic surfaces or at oxide-metal interfaces anywhere inside battery where be: e^-, p^+ and metals	Require local presence of hydrogen (protons), metals, and surface plasmon or π electrons	2 nanometers (*nm*) to as large as ~100⁺ microns (μ) in diameter; roughly circular in shape	MeV-energy nuclear reactions occur within	~3,700 up to ~5,700	Directly radiate infrared heat photon energy; ionizes nearby molecules, materials, destroys μ-scale nanostructures

"For the truth of the conclusions of physical science,

observation is the supreme Court of Appeal."

Sir Arthur Eddington

"*The Philosophy of Physical Science*" pp. 9 (1939)



Model Dendrites