De-materialization and Communication: Minerals in LED as Architectural Materials

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Introduction

The materials used in architecture have changed dramatically from the traditional masonry to steel and glass. The advance in technology and the discovery in chemistry provide new materials, such as various types of minerals, which used in the modern buildings. With the requirements of energy-efficient and low costing, the proliferation of new energies and new materials in architecture seems to be unavoidable. One of them is LED, the invention of which either replaces the incandescent lamps for interior lighting or is used on the facade as billboards. Thanks to modern chemistry that do research on the minerals purify and on compound production, the minerals used in LED became diversified with different-colored lighting produced. The minerals and the technology create new streetscape, bring new functions to the architecture and change people's perception of the built environment. This paper will focus on the minerals used in light-emitting diode (LED) in architecture, mainly gallium and boron, finding the main mines of these minerals and figuring out how they are used in LED lighting by introducing the working principle of LED. The history and the contemporary conditions of the two minerals will also be included, which are related to the development of LED technology. With the context of architectural development in the late twenty century, this article will use Times Square as a an example to demonstrate the impact of using the minerals in the form of LED on changing the urban landscape. In addition, One Times Square, as a landmark in Times Square, will be used to illustrate the impact of using LED on changing the architectural concepts of individual buildings. The

application of chemical elements, gallium and boron, makes LED lighting more colorful and energy-efficient. As a result, the application of LED lighting can be wide-spread. The quality of LED billboards is also improved. Eventually, the effects of using minerals and using LED in the architecture are reflected on the changes of streetscape and buildings, which are related to the commercial development. The streetscape is changed from static to dynamic, from monotonous to multi-sensory. The buildings become the support of information and have a new function of communication.

The invention of LED lighting, working principle and the primary minerals

Based on the previous scientific discoveries about display technology, the first step of inventing light-emitting diodes was started in 1961, namely Robert Biard and Gary Pittman discovered the first infrared LED light, although the invisible light did not have any practical use[1]. Just after one year, Nick Holonyack produced the first visible LED light, earning the title of "Father of the Light-Emitting Diode"[2]. From 1960s to 1970s, experiments using different semiconductor materials to produce LED lighting with different colors made this technology well-established. Another outbreak of LED development history is the invention of blue lighting LED, which was not commercially used until 1980s[3]. The invention of LED screen and video even takes more time to be available. It was only when Shuji Nakumura, then at Nichia Chemical, announced the availability of the blue LED based on the chemical component, Indium Gallium Nitride, that possibilities opened for big LED video displays[4].

Different types of LEDs were produced with the technology and materials for

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[1] "Then and Now: The History of Display and LED Technoloy," *Konica Minolta*. Feb, 23, 2022. https://sensing.konicaminolta.us/us/blog/then-and-now-the-history-of-display-and-led-technology/

[2] "A Brief History of LED Lighting," *ShineRetrofits*. Feb, 23, 2022. https://www.shineretrofits.com/knowledge-base/lighting-learning-center/a-brief-history-of-led-lighting.html

[3] https://en.wikipedia.org/wiki/Light-emitting_diode.

[4] https://en.wikipedia.org/wiki/Light-emitting_diode.

manufacturing evolved, from the low-power LEDs to the recent blue LED. The paper would focus on the minerals used by RGB LEDs, which is a widely-used, mature technology and has a significant effect on exterior streetscapes, especially in commercial environment like Times Square. The importance of minerals for LED is that different minerals used in the semiconductor determine the colors of the lighting. The structure of a typical LED consist of P- layer semiconductor, N-layer semiconductor and active layer in-between[5]. Silicon is the basic mineral, and other minerals are added in the active layer as dopant. Energy differences between P-layer and N-layer are caused by the dopant, so that the movement of electrons can cause different colors[6]. Although there are various elements added in silicon to produce mlti-colored lighting, red, green and blue lighting all require gallium. Gallium is a necessary element for RGB LED, which is usually used as microelectronic components including gallium arsenide (GaAs) or gallium nitride (GaN)[7]. These components used in LED cannot be replaced by other effective materials[8]. With LED technology developing to pursue lower cost and higher efficiency, another element, boron, was added into silicon[9].

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[5] https://en.wikipedia.org/wiki/Light-emitting_diode.
[6] https://en.wikipedia.org/wiki/Light-emitting_diode.
[7] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.
[8] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.
[9] "Can Boron Increase the Efficiency of LEDs?" accessed April 29 2022. https://compoundsemiconductor.net/article/102938/Can_Boron_increase_the_efficiency_of_LEDs.

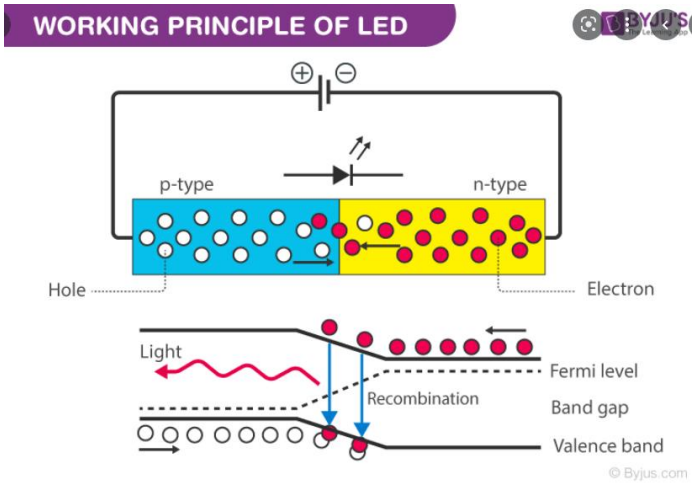

Figure 1. The working principle of LED lighting (Source:

https://en.wikipedia.org/wiki/Light-emitting_diode)

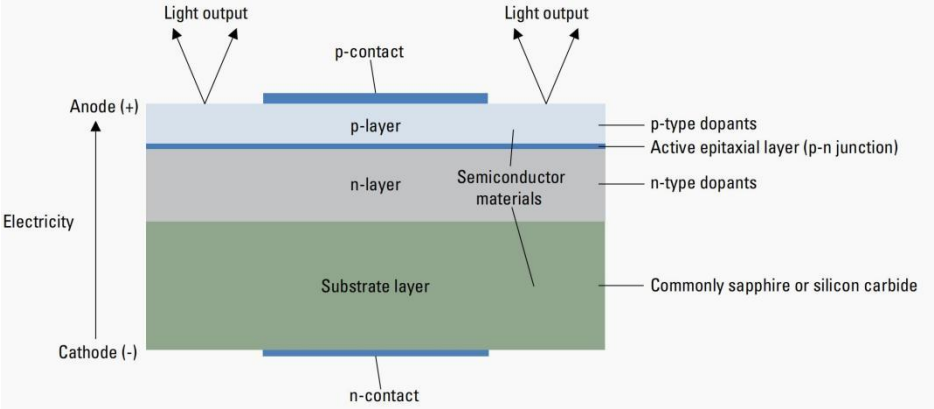

Figure 2. Structure of a LED chip (Source: Byproduct Metals and Rare-Earth Elements Used In the Production of Light-Emitting Diodes)

The amount of gallium in minerals is rare, so that this element is not mined but is obtained from the processing of other metals, such as aluminum, zinc and copper, as a by-product[10]. The low-purity gallium need to be refined again so that high-purity gallium will be obtained and used in LED. Currently, gallium can be derived in the processing of bauxite ore for aluminum and in the processing of sphalerite ore for zinc[11]. These two types of

[10] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.
[11] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.

minerals provide the majority of newly mined gallium metal[12]. St. George Mining operated a mine and processed plant to recover gallium contained in iron oxide minerals, but this company was temporarily closed in 1987 and went bankruptcy later[13]. From then on, although gallium is an essential element, there is no domestic primary gallium discovered since 1987 in the U.S.[14]. As a large consumer of gallium with thirty percent of gallium used to produced LEDs and laser diodes, the U.S. relies on other countries and the global trading to obtain gallium[15]. The current way of obtaining gallium is importing low-purity, unrefined gallium from countries including China, Russia, and Ukraine, and refining high-purity gallium. Besides the technological advances, from the perspective of material supply and manufacture, the international cooperation, the modern transportation, and the cross-continent trading all contribute to the application of gallium in LED lighting in the U.S.. There are some regions in the U.S. where bauxite deposit and zinc deposit can be potentially mined, including Upper Mississippi Valley, Viburnum Trend Austinville, Apex, Ruby Creek and Red Dog[16]. But these regions need to be mined further and may provide domestic gallium in the future. More refinery companies appeared in the U.S. from the late twenty century, including Sulzer Brothers Inc. in Gramercy, California, replying on bauxite from Jamaica as its feed source, Rhone-Poulenc at Freeport, Taxes, replying on gallium from Australia as feedback and Recapture Metals Inc. In Blanding, Utah[17].

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[12] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.

[13] Kramer, Deborah A.. *Gallium and Gallium Arsenide: Supply, Technology, and Uses*. (University of Michigan Library,1988), p.21.

[14] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.

[15] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.

[16] U.S. Department of the Interior. U.S. Geological Survey. "Gallium: Chapter H of Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply." USGS. 2012.

[17] Kramer, Deborah A.. *Gallium and Gallium Arsenide: Supply, Technology, and Uses*. (University of Michigan Library,1988),

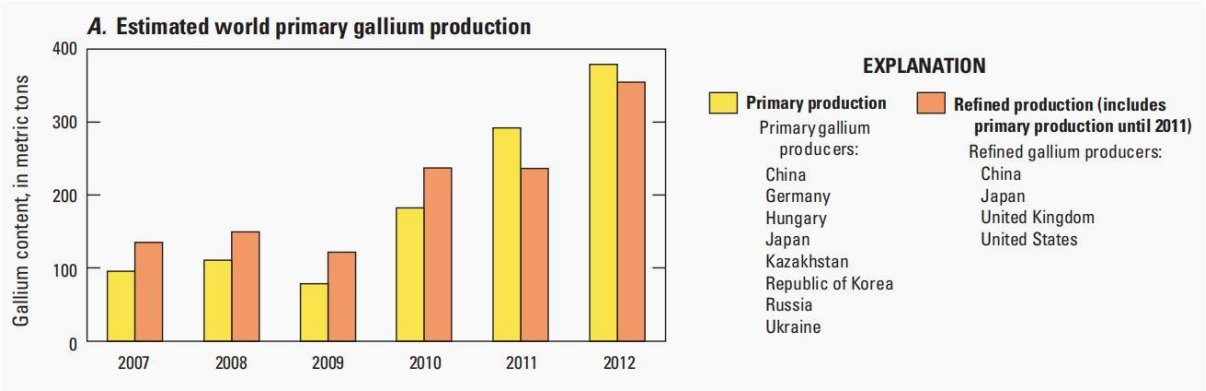

Figure 3. Estimated world primary gallium production (Source:Gallium: Chapter H of Critical Mineral Resources of the United States)

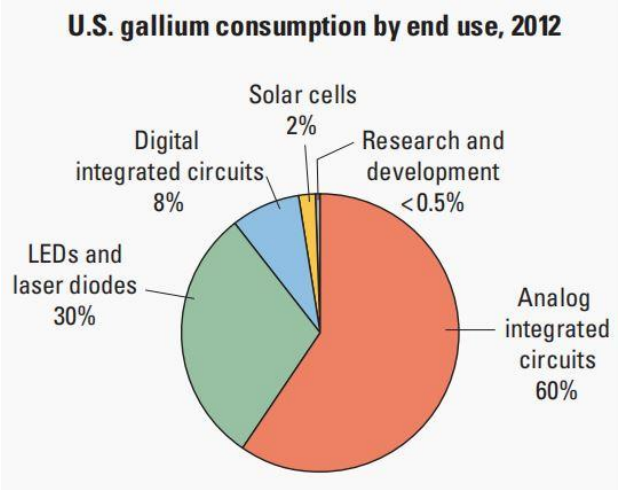

Figure 4. U.S. gallium consumption by end use (Source:Gallium: Chapter H of Critical Mineral Resources of the United States)

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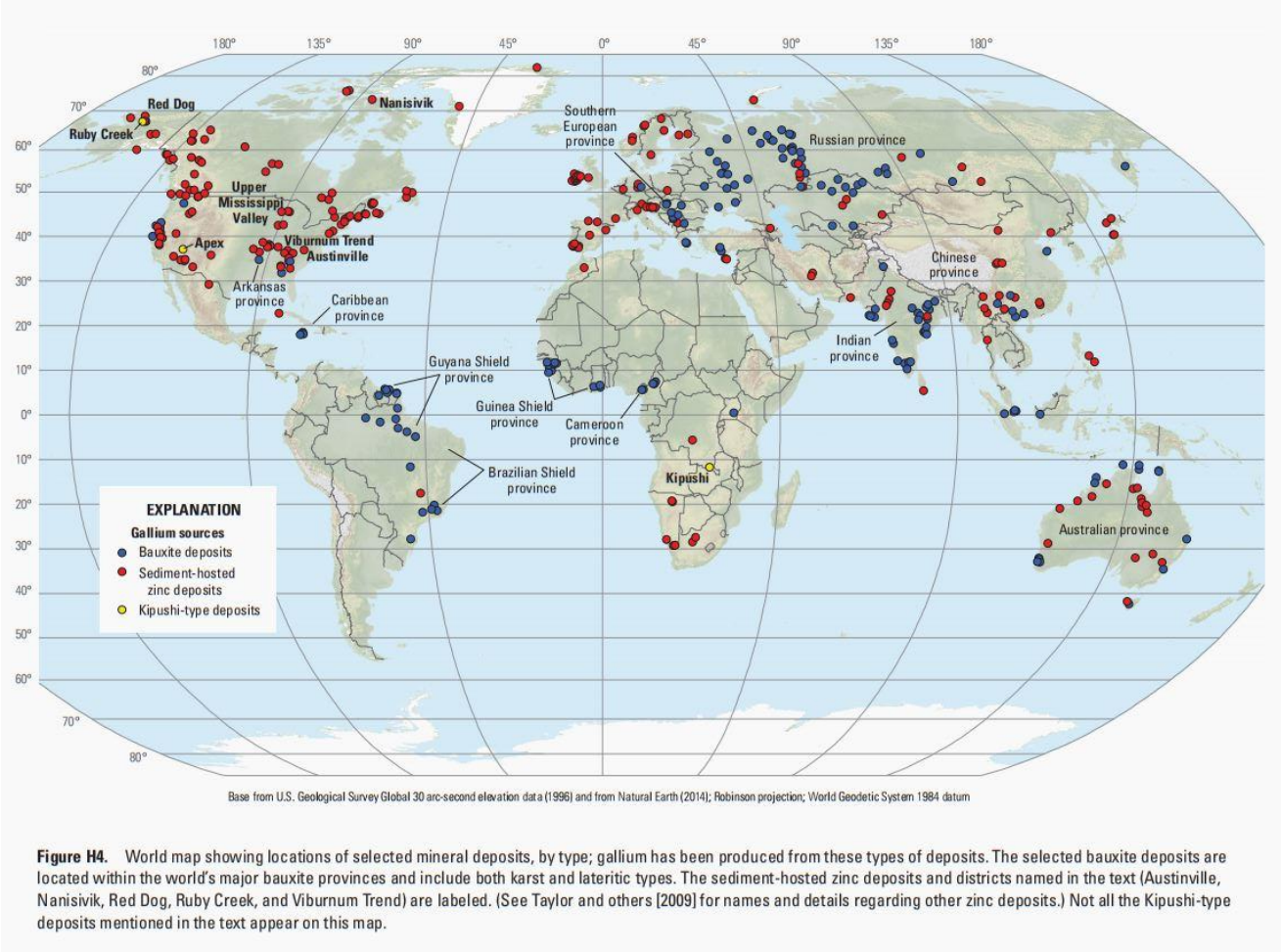

Figure H4. World map showing locations of selected mineral deposits, by type; gallium has been produced from these types of deposits. The selected bauxite deposits are located within the world's major bauxite provinces and include both karst and lateritic types. The sediment-hosted zinc deposits and districts named in the text (Austinville, Nanisivik, Red Dog, Ruby Creek, and Viburnum Trend) are labeled. (See Taylor and others [2009] for names and details regarding other zinc deposits.) Not all the Kipushi-type deposits mentioned in the text appear on this map.

Figure 5. The global location of mineral deposits which can produce gallium.

(Source:Gallium: Chapter H of Critical Mineral Resources of the United States)

By contrast, the U.S. is one of the biggest producers of the other element, boron, so that "most of the boron products consumed in the United States were manufactured domestically"[18]. The origin of the majority of borate ore is southern California, while the minerals and chemicals are principally consumed in the northcentral and eastern United States[19]. It is claimed that the Death Valley in California used to contain nearly half of the known borate ore in North America, which has been mined in 1864 as a commercial

[18] U.S. Geological Survey, "Mineral commodity summaries 2022: U.S. Geological Survey," USGS, accessed in April 29, 2022. https://doi.org/10.3133/mcs2022.

[19] U.S. Geological Survey, "Mineral commodity summaries 2022: U.S. Geological Survey," USGS, accessed in April 29, 2022. https://doi.org/10.3133/mcs2022.

product[20]. The initial development of mining borate was not that prosperous, because of the limited amount of discovered borate, the lack of transportation and the harsh climatic conditions making the exploitation uneconomic[21]. Later, more borax deposit were mined. For example the discovery of borax in Furnace Creek in 1881 helped the operation of Harmony Borax Works, Amargosa Borax Works and Eagle Borax Works[22]. Another larger deposit east of the Greenwater Range and southwest of Death Valley Junction was found, which contributed to the revolution of the borax industry in the United States[23]. As a result, more sophisticated underground mining methods and techniques were developed to mine the more concentrated deposits[24]. A new railroad reached this underdeveloped region, namely the Death Valley Narrow-gauge Railroad operating from Death Valley Junction to the newly-opened mines[25]. When the Death Valley Junction concentrating plant shut down in 1928, the prosperous era of borax production in the Death Valley ended. It was not until 1971 when Tenneco, Inc., started open-pit operations at the Boraxo Mine near Ryan that borax mining continued in the area[26]. There are two companies in California producing boron nowadays, thanks to the Death Vally and the economically viable deposits in the Mojave Desert[27].

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[20] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[21] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[22] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[23] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[24] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[25] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[26] "Borax Mining in Death Valley, California," accessed by April 29, 2022. https://www.batcon.org/article/death-valley-roots/

[27] U.S. Geological Survey, "Mineral commodity summaries 2022: U.S. Geological Survey," USGS, accessed in April 29, 2022. https://doi.org/10.3133/mcs2022.

Figure 6. 20-Mule Team hauling Borax in Death Valley (source: https://www.legendsofamerica.com/ca-boraxmining/)

Figure 7. Ore cart in California (Source: https://www.legendsofamerica.com/ca-boraxmining/)

Case study: The application of minerals in Times Square

The requirement of energy-efficient, low-costing lighting resulted in the proliferation of LED. The discovery of gallium and boron minerals and their applications in semiconductors make the wide-spread usage of LED lighting possible. The application of LEDs in the district,

in turn, reshapes the urban landscape, such as Times Square. The application of LED billboards on the facade changes the perception of architecture.

The Urban Landscape of Times Square

Although advertising, billboards and signs appeared in Times Square in the early days, LED lighting changed the static physical streetscape into dynamic and informative, creating the so-called "the world capital of sensory overload" with the spellbinding video and sounds. Between 1882 and 1893, five spaces opened between Thirty-eighth and Forth-first Streets: the Metropolitan Opera, the New York Casino, and theaters named the Broadway, the Empire, and Abbey's[28], which determined the location of nowadays Times Square. This region has attracted merchants since the 1890s, when they use electric lights for signage and huge wooden billboards with brightly colored pictures for advertising[29]. Particularly, "The blocks surrounding the corner of Forty-second Street, Broadway, and Seventh Avenue become important advertising platforms"[30], where the billboard and signs was hung so high that they could be seen from all directions and from the distance. The first large electric sign of appeared on the large north wall of a hotel on the twenty-third street[31]. During this period, although buildings were partly covered by the signs, this district mainly consisted of actual buildings, and the physical walls as clear boundaries divided the inside and the outside.

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[28] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 4.
[29] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 4.
[30] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 4.
[31] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 30.

Figure 8. The first giant electric signs (Source:Times Square Spectacular)

The merchants continued to use electronic signs, which became giant because the movie industry developed in this region in the 1920s[32]. Many corners were covered with billboards, "which were placed in floodlighted frames and topped with amazing spectaculars"[33]. With the larger, brighter billboard of advertising, the physical wall started to be vague, which means that the boundary between the inside and the outside started to disappear and the static status of the district was changed.

[32] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 75.
[33] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 75.

Figure 9. The giant movie signs in Times Square (Source: Times Square Spectacular)

The late 1930s witnessed another development of the streetscape. Thanks to the invention of a new lighting medium, neon, "the basic street formula of billboards, vertical signs, animated spectaculars, elaborate marquees, and lighted storefronts continued to be the rule Times Square"[34]. During this period, one figure that promoted the change of streetscape was Douglas Leigh. Inspired by the New York World's Fair, Leigh tried to combine moving pictures with advertising signs and "imagined buildings mounted with enormous spectacular-like signs playing cartoons"[35]. Leigh used a technology called Leigh-Epok, successfully produced the first filmed cartoon signscape and used another typed of animated advertisement named the Wonderdesign[36]. Starting from Leigh's idea of using animated cartoons as advertisement, the streetscape was converted from static to dynamic. The physical wall did not function as a boundary but a platform to display.

[34] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 97-98.
[35] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 106.
[36] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 109.

Leigh's idea of creating outsized urban and environmental spectacles with large, animated advertisement was continued in the 1970s, for example, the spectacular billboard featuring a Gordon's Gin bottle[37]. In 1976, a large computer-operated screen, called the Spectacolor sign, went up on the north end of the Times building, a harbinger of the huge television screens in Times Square today"[38]. Leigh's idea even influenced the zoning regulation. In 1986, the planning commission, after studying streetscape of Times Square, put forward a zoning regulation that all new buildings in the so-called "Bow-Tie zone" should reserve an amount of space for animated electric signs, mandating "ratios of signs of facades, street heights, light levels, and placement of signs"[39].

With the enlightenment of Leigh's idea and the zoning, the application of LED display and its popularity in the Times Square would be inevitable. Computer-controlled architectural signage, enormous multistory signs and huge screens, which gives a different texture of the streetscape, all rely on LED technology and minerals. Through LED, "Times Square has become a center in which buildings have become signs and news, live sports events and advertisements are broadcast night and day, as Douglas Leigh imagined sixty years ago"[40].

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[37] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 146.
[38] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 146-147.
[39] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 157.
[40] Darcy Tell. *Times Square Spectacular*. (HarperCollins. 2007) 161.

Figure 10. Current streetview of Times Square

(Source:https://www.campaignlive.com/article/history-advertising-no-149-times-square/1367381)

With the materials of advertisement billboards in Times Square changed from electric signs to neon billboard to LED video eventually, the streetscape is also changed accordingly. In the contemporary city, what shaped the physical environment seems not to be the buildings and streets themselves. In the period of commercial development and information exploration, the merchants make full use of the public space to promote and to attract people's attention. If the physical building consist of the primary layer of the Times Square, LED billboard would be the second layer, converting the contemporary cities to an ephemeral stage "where every surface seems to be functional to a theatrical performance aimed to astonish and communicate"[41]. LED billboards provide fragmentary, non-linear and multi-sensory information that make visitors feel they enter a space constructed by information rather than by physical materials.The discovery of gallium which makes LED lighting colorful and the

[41] Katia Gasparini. "Media Façades and the Immersive Environments," Wolkenkuckucksheim, Internationale Zeitschrift zur Theorie der Architektur 19, (2014): 251-263. https://www.researchgate.net/publication/270281488_Media_Facades_and_the_Immersive_Environments/citation/download

discovery of boron which makes LED lighting more efficient contribute to the realization of media façades, and the merchants' desire of disseminating information.

The Building, conceal, media facade

The application of LED lighting not only changed the streetscape but also the function and perception of individual buildings. The walls seem not function as boundary to define space, because the LED billboards covering these walls open another space where people can get more information. In other words, LED achieved the immateriality of the architecture, converting the building into a conveyor of information rather than a living space.

The changes happened on the facade of Time Square One would be served as an example. As a typical steel skeleton frame building established in 1903 with stone and terra cotta, Times Square One provided working space for the headquarters of The New York Times[42]. It became a landmark of the region because of its height and location. What the pedestrians could perceive was the form of the building and the physical facade. The solid curtain walls distinguished the interior from the exterior. When it came to 1977, as the advertisement developed, billboard appeared, partly concealing the facade of the building. The building had another function of supporting the billboard besides providing working places. From 1995, a new purpose of redeveloping One Times Square was adding advertising billboards on its facade to take advantage of its prime location[43]. In 2017, the original facade of Times Square One has been largely covered by LED billboards. These billboards fragmented the real facade so that the differentiation between the inside and the outside is diminished. The communication function of the architecture has been emphasized. What

[42] https://en.wikipedia.org/wiki/One_Times_Square#Times_ownership.
[43] https://en.wikipedia.org/wiki/One_Times_Square#Times_ownership.

people can conceive is the information rather than the physicality of the building. The original function of the building cannot be perceived from the facade and the form, and the value and the status of this building is not determined by its location and the place it can provided but by the information it can determinate and the attention it can obtained from the pedestrians. As Venturi said the signs are antispatial; "it is an architecture of communication over space; communication dominates space as an element in the architecture and in the landscape"[44]. In addition, Time Square One is also the place where the New Year's Eve "Ball Drop" happens annually[45], which also relies on LED technique. Because this event, the building seems to be more well-known and became a focal point of the city. The application of LED seems change the standards of landmarks. Before, the significance of a building is related to its design, form and function. After the high technology equipment is attached to the building, the importance of a building seems to be related to the value that the building can generate and the events or human activities that LED lighting can stimulate around the building. Times Square One can continue to be a landmark in the modern city, partly because the LED billboards have commercial value, and because the "Ball Drop" is impressive and eye-catching so that people would gather around to celebrate a big event.

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[44] Robert Venturi, Denise Scott Brown, Steven Izenour, *Learning From Las Vegas: the Forgotten Symbolism of Architectural Form*, (The MIT Press, 1977), 13.

[45] https://en.wikipedia.org/wiki/One_Times_Square#Times_ownership.

Figure 11. Times Square One under construction (Source: Wikipedia Commons)

Figure 12. Times Square One in 1919 (Source: Wikipedia Commons)

Figure 13. Times Square One in 1977 (Source: Wikipedia Commons)

Figure 14. Times Square One in 2017 (Source: Wikipedia Commons)

Conclusion

Compared with the traditional lighting like incandescent lamps, the use of light-emitting diodes is more environmental-friendly and cost-savings. The high-quality lighting, the longer

life and the reduced power consumption of LEDs rely on the discovery of various minerals, among which gallium and boron are two essential ones.

Gallium can only be obtained in trace amounts in zinc and aluminum ores. The production of different-colored LED lighting rely on gallium components, namely gallium arsenide and gallium nitride. As there is no domestic gallium discovered in the U.S., gallium is completely rely on import and can be refined. The deposit of boron in the U.S. is rich, considering the history of mining boron can be traced back to the nineteen century in the Death Valley in California. Although the mining of borax used to be eased in the Death Valley, it was resumed in the 1907s and the production of boron still concentrates in California currently.

The use of gallium and boron contributes to the proliferation of using LED in building in Times Square, which is under the social background of the Information Age. People pursue sensory experiences and are overwhelmed with plenty of information. Under such circumstance, "architecture has become a support of print and electronic media. It begins to take on a more recognized communicative function"[46]. Marshall McLuhan put forward the idea that "the medium is the message"[47]. LED technology makes buildings and the public space become the medium of conveying message, providing more sensory stimuli and facilitating the creation of the world of information. Additionally, the modern merchants prefer to choose LED for the sake of profits and value. LED facade of the buildings are more eye-catching so that more human activities can be stimulated, which could be regarded as a

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[46] Katia Gasparini, "Media Façades and the Immersive Environments," *Wolkenkuckucksheim, Internationale Zeitschrift zur Theorie der Architektur* 19, (2014): 251-263. https://www.researchgate.net/publication/270281488_Media_Facades_and_the_Immersive_Environments/citation/download

[47] Marshall McLuhan, *Understanding media: the extensions of man* (Corte Madera: Gingko Press, 2003).

new standard of the value of building under the context of commerce development in the contemporary metropolitan.

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