LED semiconductor engineering in light-curing of resin-based restorative materials in dentistry

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Abstract– ***The application of light-emitting diodes (LEDs) has evolved, and their use has been incorporated into different sciences, one of which is dentistry. The objective is to propose a solution of LED semiconductors based on the engineering of LED circuits to formulate a prototype of a third-generation light-curing unit with adequate energy efficiency, within the electromagnetic spectrum of blue-violet light to carry out an effective light-curing of resin-based restorative materials; also, a long working life, innovative design and low cost. To collect data on the daily clinical practice and use of LED light-curing units, a survey was conducted with 32 health professionals in the dental field (among dentists, bachelors in Dentistry and dental students). According to the data obtained, together with the theoretical information, this research describes the proposal for the design of an arrangement of LED semiconductors - plate of 5 miniature Blue-Violet chips (Packing of LEDs - OSTAR LIGTHNG) to be considered for the implementation in the dental field, in order to propose a prototype of a more efficient LED light-curing unit, with lower costs and that meets the conditions expected by dental professionals. It is concluded that the engineering associated with the technological evolution of LEDs can contribute to the improvement of equipment, systems, and devices used in dental treatments.***

Keywords- LED semiconductor, polymerization, radiant emittance, light curing unit.

I. INTRODUCTION

There is no doubt that LED has turned the world of lighting upside down. Although at first, many were skeptical due to the low initial performance, its rapid evolution in recent years has made it the absolute market leader, overtaking any other technology.

One of the fields where LED semiconductors have been incorporated is in dentistry. In 1995, an innovative initiative appeared that includes the light-curing of dental materials through light emitted by diodes, in which semiconductor fusions are used to produce blue light; in addition to generating less heat and less energy consumption. LED LCUs (light curing unit) emit light with a wavelength of 400 to 500 nm, a range very close to the absorption of photoinitiators added to resin composites and other photocurable materials.

Dentists need a LCU that meets all the necessary characteristics to produce an adequate polymerization. Currently, there is a wide variety of LED LCUs sold around the world and these are displayed in a myriad of presentations and exhibit different qualities. However, lack of knowledge of this wide variety of restorative equipment and materials available on the market, as well as their various properties, could lead to an incorrect use of this technology, which will adversely affect the restorations carried out.

This research rationale comes from the point of view that the use of LED LCUs for light-curing resin-based restorative materials has a direct effect on their longevity and on their mechanical and physical properties.

The applications of new LED technologies that provide great contribution to the clinical management of light-curing restorative materials in dentistry, and that mark a range of possibilities of invaluable importance in dental procedures are reviewed.

The objective is to propose a suitable solution of LED semiconductors based on the engineering of LED circuits in order to describe a prototype idea of a third generation LCU with adequate energy efficiency, within the electromagnetic spectrum of blue-violet light to carry out an effective polymerization of resin-based materials; in addition, a long working life, innovative design and low cost.

As support for the research, theses, articles and scientific journals have been reviewed, [1] evaluated the distribution of light intensity at the tip of 3 LED LCUs, finding that both were different in the 3 LCUs studied. Likewise, [2] studied the influence of the emission of different wavelength spectra (a LCU that emits blue light vs a LCU that emits blue and violet light) and concluded that LCUs that emit light in a broader spectrum (blue light and violet) positively influenced the polymerization of resin composites containing alternative photoinitiators. In addition, [3] determined the effect of 4 LED LCUs with different characteristics and found that the use of a tip with a larger diameter that can cover the entire tooth and a homogeneous light beam distribution are the characteristics most important when polymerizing a resin composite.

The results obtained from the evaluations of the different characteristics of LED LCUs have allowed us to present a proposal for a novel solution to implement in LCU technology used in dentistry.

II. STATE OF THE ART

LED semiconductors are solid state devices of great resistance, when receiving a very low intensity electrical current, efficiently emit light with high performance (LED stands for Light Emitting Diode). These LEDs have very important characteristics such as: greater energy efficiency, greater resistance to vibrations, less risk to the environment, and the ability to operate continuously intermittently. Also, it is possible to produce lights of different colors with a high luminous efficiency, unlike many of the lamps used up to now, which have filters to achieve a similar effect [4].

The semiconductor material is layered in the form of a p-n junction, as shown in Fig. 1.

When a suitable voltage is applied to the wires, the electrons can recombine with the holes within the device, releasing energy in the form of photons. Due to this, they receive the name of light-emitting diode or LED. All diodes can emit electromagnetic radiation [4].

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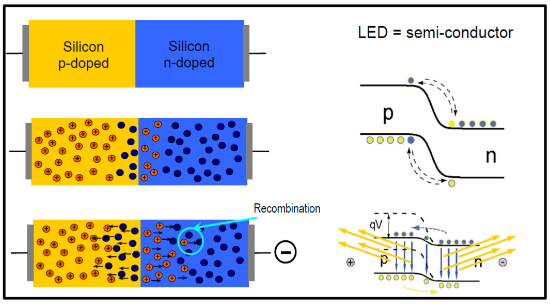


Fig. 1 Principle of light emission (Light Emitting Diode). [4]

The luminous intensity of an LED will increase with the forward current until a saturation point is reached where any further increase in current does not effectively increase the illumination level, as shown in Fig. 2 [4].

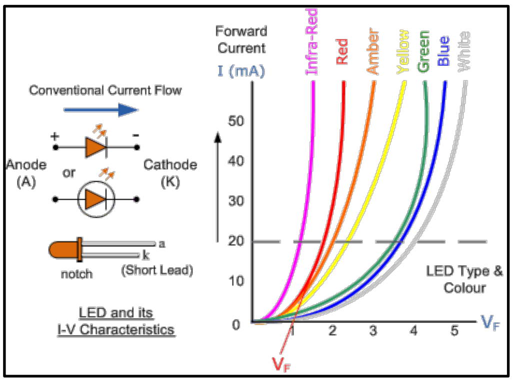


Fig. 2 Response curve of the LED diode. [4]

The semiconductor materials used in LEDs are selected to emit in the visible range, Fig. 3. Thus, different materials produce light with different wavelengths and, therefore, different colors [4].

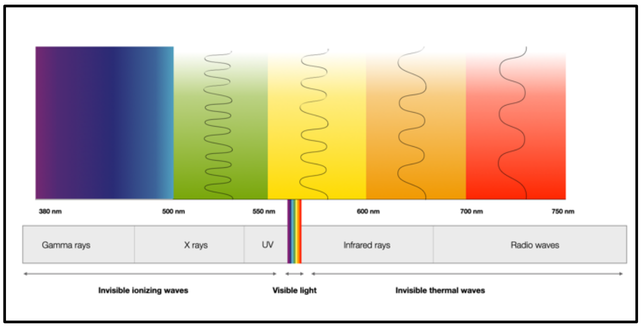


Fig. 3 Visible light spectrum. [4]

Today, LEDs offer many advantages over conventional sources of incandescent or fluorescent lights, highlighting a lower energy consumption, a longer working life, an improved physical robustness, a smaller size as well as the possibility of manufacturing them in very diverse colors of the visible spectrum in a much more defined and controlled way; in the case of multi-colored LEDs, with a fast-switching frequency [4].

These LEDs are now used in such diverse applications covering all current technological areas, from bioengineering, medicine and health, through nanotechnology and quantum computing, electronic devices or light-curing in dentistry, of which the present investigation is about.

Blue LEDs were first developed by Henry Paul Maruska of RCA in 1972 using Gallium Nitride (GaN) on a sapphire substrate. The SiC type (made with silicon carbide) began to be marketed by Cree, Inc., in The United States in 1989. However, none of these blue LEDs were very bright [5].

The first high brightness blue LED was introduced by Shuji Nakamura of the Nichia Corp. in 1994 starting from the material Indium-Gallium Nitride (InGaN).

Isamu Akasaki and Hiroshi Amano in Nagoya worked in parallel, in the crystalline nucleation of Gallium Nitride on sapphire substrates, thus obtaining p-type doping with said material.

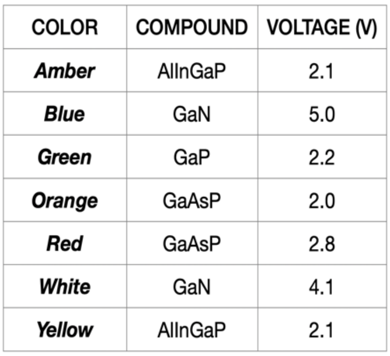
In 1995, Alberto Barbieri from Cardiff University (UK) laboratory was investigating the efficiency and reliability of high brightness LEDs and as a result of the research he obtained a LED with a transparent contact electrode using indium tin oxide (ITO) on aluminum-gallium-indium phosphide and gallium arsenide.

In 2001 and 2002, processes were carried out to grow gallium nitride LEDs in silicon. As a result of these investigations, Osram launched high power gallium indium nitride LEDs grown on silicon substrate in January 2012.

A coherent visible light can be generated by other combinations of elements. Table I provides a list of common compound semiconductors and the light they generate. It also includes the range of forward polarization potentials of each one [4].

In the investigation, we will take as a reference the polymerization of resin-based materials that are carried out by blue and violet light lamps.

TABLE I
COMMON LED COMPOUNDS AND THE LIGHT THEY GENERATE



COLOR	COMPOUND	VOLTAGE (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	2.8
White	GaN	4.1
Yellow	AlInGaP	2.1

Source: Boylestad y L. Nashelsky [4]

The light output and efficiency of nearby blue and ultraviolet LEDs increased while the cost of lighting fixtures manufactured with them fell, leading to the use of white light LEDs for illumination, Fig 4. The White LEDs can produce 300 lumens per electrical watt at a time that can last up to 100,000 hours. Compared to incandescent bulbs this represents not only a huge increase in electrical efficiency but also a similar or lower cost per bulb [5].

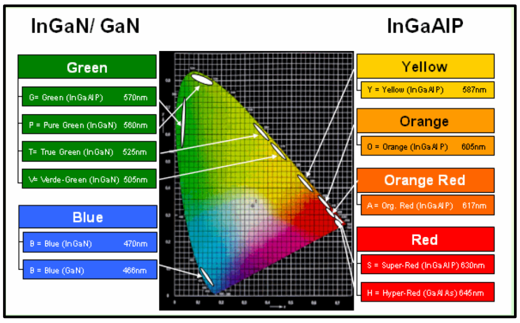


Fig 4. Color emission according to the type of material [5]

Circuit arrangement with LED diodes

Series Arrangement: [5] - The diodes can be connected in series as long as the sum of the voltage drops is less than the supply voltage, Fig. 5.

Advantages: same current, same luminous flux and same light intensity for all LEDs.

It can be easily implemented with a more efficient riser topology; however, losses are evaluated with: (1)

$$\text{Losses} = \text{VBallast} * I_D \;.... \quad (1)$$

Disadvantages: You need to raise the voltage a lot if you put many LEDs, EMI (Electromagnetic interference) problems occur.

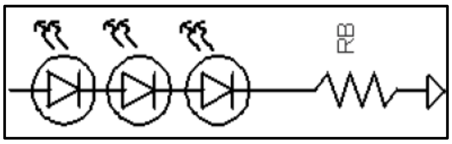


Fig. 5 Connection of several LEDs in series. [5]

$$V_D = I_D * R \qquad .... (2)$$

$$R = (VCC - NV_D)/I_D \quad ---- \quad (3)$$

Where: N is the number of LEDs connected in series.

VD = Diode voltage

R is the bias resistance

VCC is the circuit power

ID is the diode current

Joule's Law is also defined, by the formula:

$$\text{Power} = I^2R \qquad .... \quad (4)$$

Where:

I is the intensity and R the resistance

Parallel Arrangement: [5] - To connect several LEDs in parallel we will only have to calculate the value for one LED, in this case we must be careful with the intensity of the power supply that must be greater than the sum of all the LEDs, Fig. 6.

Advantages: It does not pass the same current (different elbow voltages and direct resistance), different luminous flux, semiconductors must withstand a lot of voltage so they are more expensive, low voltage semiconductors can be used to be cheaper.

Disadvantages: The current of each LED must be regulated to ensure that they all emit the same light intensity

$$\text{Losses} = N * \text{VBallast} * I_{LED} \;...... \quad (5)$$

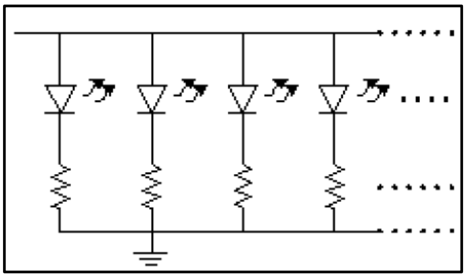


Fig. 6 Connecting multiple LEDs in parallel [5]

Mixed array of LEDs [5]

Advantages: It is interesting if you want to use many LEDs. Only one branch is current regulated. The voltage drop across the other diodes sets the current in the other branches. Disadvantages: The differences in voltage of the diodes make it appear brighter in some branches than in others, Fig. 7.

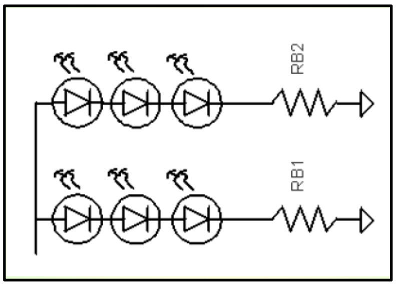


Fig. 7 Series-parallel connection of several LEDs [5]

Types of LEDs

The different types of LEDs come in different shapes and sizes, but the most used and common are the 3mm, 5mm and 8mm LEDs, these come available in various colors such as red, blue, yellow, green, white and others. The most commercially available are the following: [7]

SMD LEDs (Surface-Mounted Device): These LEDs combine the three RGB colors in a single package. Thanks to this, small pixels are achieved. These SMD LEDs are special packages that can be easily surface mounted on a PCB board. They generally differ according to their physical dimensions. For example, the most common are 3528 and 5050 SMD LEDs [7].

High Power LEDs: A LED with a power rating greater than or equal to 1 watt is called a high-power LED. This is because normal LEDs have a power dissipation of a few milliamps. High-power LEDs are very bright and are often used in flashlights, car headlights, spotlights, and others. High-power LEDs HP-LED (High-power LED) or high emission HO-LED (English High-Output LED) can be controlled with currents from hundreds of mA to more than 1 Ampere, while other LEDs only reach to the tens of miliAmps. Some can emit more than a thousand lumens [7].

Phosphor-based LEDs: This method involves coating LEDs of one color (mainly blue InGaN LEDs) with phosphors of different colors to produce white light.

Miniature LEDs are often used as indicators. In through hole technology and surface mounts, their size ranges from 2mm to 8mm. They usually do not have a separate heat sink [7].

The maximum current is between 1mA and 20mA. Its small size is a limitation in terms of the power consumed due to its high-power density and the absence of a heatsink. They are often daisy-chained to form led light strips. There are three main categories of single-color miniature LEDs.

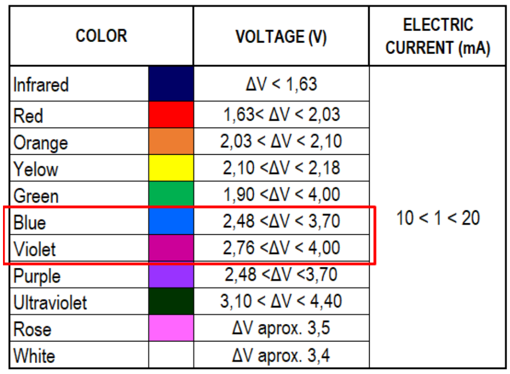
Low Current Intensity - Prepared for a current of 2mA with about 2V (consumption of more or less 4 mW).

Intermediate or Common Range - 20mA LEDs (between 40mW and 90mW) around: 1.9-2.1 V for red, yellow orange and traditional green. 3.0-3.4 V for pure green and blue and 2.9-4.2 V for violet, pink, purple and white.

High Current Intensity - For a current of 20mA and with 2 or 4-5 V, designed to be able to see in direct sunlight.

The 5V and 12V LEDs are normal miniature versions that incorporate a series resistor for direct connection to a 5 or 12V power supply, Table II, [7].

TABLE II
VOLTAGE AND CURRENT OF THE LEDS



COLOR		VOLTAGE (V)	ELECTRIC CURRENT (mA)
Infrared	🟦	ΔV < 1,63	10 < 1 < 20
Red	🟥	1,63< ΔV < 2,03	
Orange	🟧	2,03 < ΔV < 2,10	
Yelow	🟨	2,10 <ΔV < 2,18	
Green	🟩	1,90 <ΔV < 4,00	
Blue	🟦	2,48 <ΔV < 3,70	
Violet	🟪	2,76 <ΔV < 4,00	
Purple	🟪	2,48 <ΔV <3,70	
Ultraviolet	⬛	3,10 < ΔV < 4,40	
Rose	🟪	ΔV aprox. 3,5	
White	⬜	ΔV aprox. 3,4	

Source: [7]

Variable Dimensions: Semiconductor LED

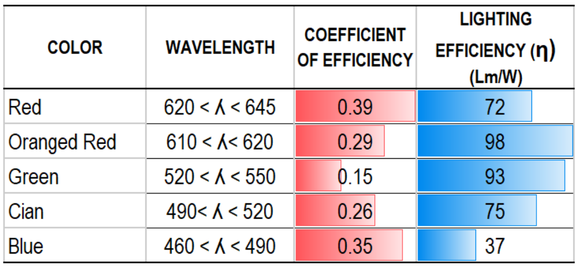
Energy efficiency

One of the main advantages of LED light sources is high luminous efficiency. The white LEDs quickly matched and even exceeded the efficiency of standard incandescent lighting systems. In 2002, Lumileds manufactured five-watt LEDs, with a luminous efficiency of 18-22 lumens per watt (lm / W).

For comparison, a conventional 60–100-watt incandescent bulb emits around 15 lm / W, and standard fluorescent lamps emit up to 100 lm / W.

As of 2012, Future Lighting Solutions had achieved the following efficiencies for some colors, Table III, [8].

TABLE III
FUTURE LIGHTING SOLUTIONS



COLOR	WAVELENGTH	COEFFICIENT OF EFFICIENCY	LIGHTING EFFICIENCY (η) (Lm/W)
Red	620 < ʎ < 645	0.39	72
Oranged Red	610 < ʎ< 620	0.29	98
Green	520 < ʎ < 550	0.15	93
Cian	490< ʎ < 520	0.26	75
Blue	460 < ʎ < 490	0.35	37

Source: [8]

The efficiency values show the light output power for each watt of electrical input power. The luminous efficiency values include the characteristics of the human eye and have been derived from the internal luminosity function. This phenomenon affects both the efficiency in the light emission of the LEDs and the efficiency in the absorption of the light of the photovoltaic cells. The refractive index of silicon is 3.96 (at 590 nm), while that of air is 1.0002926. The extraction of light constitutes, therefore, a very important aspect and in constant research and development to be taken into consideration in the production of LEDs [8].

The following aspects are important to increase the efficiency of LEDs: [5]

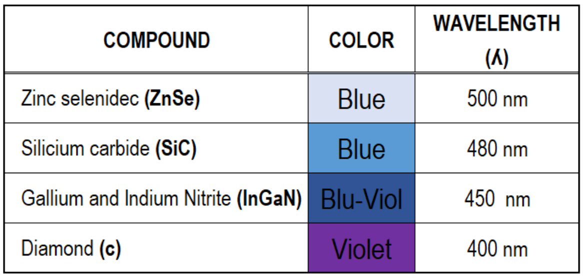
- Advances in materials with a better forbidden band.
- Better manufacturing techniques to reduce costs and increase efficiency.
- Improvements in heat dissipation
- Better extraction of light from diode materials.
- Improvements in the phosphor used to transform visible light

Wavelength

It is interesting to note that invisible light has a lower frequency spectrum than visible light.

In general, when we talk about the response of electroluminescent devices, we refer to their wavelengths and not their frequency, for the blue color the wavelength is shown in Table IV, [5].

TABLE IV
COMPUESTOS DEL LED AZUL vs LONGITUD DE ONDA



COMPOUND	COLOR	WAVELENGTH (ʎ)
Zinc selenidec **(ZnSe)**	Blue	500 nm
Silicium carbide **(SiC)**	Blue	480 nm
Gallium and Indium Nitrite **(InGaN)**	Blu-Viol	450 nm
Diamond **(c)**	Violet	400 nm

Source: [5]

The wavelength and frequency of light of a specific color are directly related to the gap in the energy band of the material. A first step, therefore, in the production of a compound semiconductor that can be used to generate light is to combine elements that generate the gap in the desired energy band [4]

$$\boxed{\lambda = \frac{c}{f}} \quad \ldots\ldots\ldots \quad (6)$$

Where:
ʎ = Wavelength
c = 3x108 m / sec (speed of light in vacuum)
f = Frequency in Hz

The wavelength and frequency of light of a specific color are directly related to the gap in the energy band of the material, Fig. 12.

$$\boxed{E_g = \frac{hc}{\lambda}} \quad \ldots\ldots\ldots \quad (7)$$

Where: h = 6.6626 10–34 J s is Planck's constant

A first step, therefore, in the production of a compound semiconductor that can be used to generate light is to combine elements that generate the gap of the desired energy band [4].

For many years the only colors available were green, yellow, orange and red, which allowed using the average values of VF = 2 V and IF = 20 mA, to obtain an approximate operating level. However, the magnitude of these two parameters changed with the introduction of blue in the early 1990s and white in the late 1990s. For blue the average forward bias voltage can be as high as 5 V and for white approximately 4.1 V, although the operating current of both is 20 mA or more [4].

Lifespan of an LED

Contrary to most conventional lamps, in well-designed fixtures, LEDs do not fail abruptly (or catastrophically). It is common for its light output to deteriorate over time [9].

Therefore, the lifetime is based on the lamp light maintenance factor (LLMF), which is the amount of light from the light source at a specific time in the future. With the advent of LED luminaires, different standards and terminologies have been established to define the useful life of conventional lamps:

- IEC 62717 => LED modules for general lighting - Performance Requirements
- IEC 62722-2-1 => Particular requirements for LED luminaires
- LM80-08 => Lumen maintenance measurement of LED light sources
- TM21 => Lumen degradation time estimation method for LED light sources
- LM80 is the approved standard for measuring the maintenance of the luminous flux of LEDs, based on a test period of at least 6,000 hours.
- The TM21 takes all this information and is used to apply an estimate of the useful life that an LED luminaire will have.

Photopolymerization

Photopolymerization consists in the chemical union of monomers to obtain high molecular weight molecules called polymers. According to [10] within the composition of resin composites, there is an organic matrix with different monomers, as well as photoinitiation systems, diluents, binding agents, polymerization inhibitors, radiation stabilizers and inorganic filler that provides physical properties for its use as restorative materials. In order for this photochemical reaction to be carried out, it is necessary for the photoinitiator to generate free radicals, these must be activated by another agent which, in the case of photocuring resin-based restorative materials, will be light at a certain electromagnetic spectrum**.**

When choosing a LCU, the dental professional must consider a series of factors: intensity, emitted wavelength, ergonomics and other additional characteristics (diameter of the light tip, whether it is wired or wireless, type of battery, working life, etc.), which are of great importance for the success of a treatment in restorative dentistry [10].

Light-curing reactions in resin-based materials are influenced by factors inherent to the resin, or external factors such as the restorative technique and the LCU used.

Resin composites come in different shades, opacities, and values. While the color of the composite resins is darker or opaque, the greater the number of pigments that cause light scattering phenomena, so a longer light exposure time is needed to achieve correct photopolymerization [10].

On the other hand, there are resin composites that are photocured with wavelengths in the spectrum of violet light, which makes second-generation lamps ineffective [11].

Likewise, the technique used when light curing is also an influencing factor. A clear example of this is that the closer the light guide is to the composite resin, the greater the penetrability of the photons and the less irradiance loss [12].

Another important factor is the amount of light energy to which the restoration is exposed, or also called irradiance (mW / cm^2), while the amount of light that is emitted from the tip of the lamp is known as radiant emittance (mW / cm^2). Ideally, a 2mm thick increment of resin composite requires a minimum radiant exposure of 16,000 millijoules / cm^2 (16 J / cm^2) [13].

The higher the irradiance, the greater the number of photons present, and consequently the greater the number of photoinitiator molecules that will be excited. Therefore, the greater the spread of polymerization in a composite resin restoration. However, it must be taken into account that increasing irradiance is not the solution to improve polymerization since this does not guarantee a total conversion of monomers to polymers and, in addition, leads to an increase in temperature that could irreversibly damage pulp tissues beneath the restoration. According to [14], the increase of 5.5 ° C in intrapulpal temperature is considered as the temperature limit that could be exerted in the tooth.

In this sense, LCUs with a radiant emittance greater than 1200 mW / cm^2 present a risk of thermal damage to vital parts [15], so it is necessary to use them with a minimum exposure time.

LED curing lights

LED technology was incorporated into dentistry approximately 20 years ago and, since then, its evolution has been divided into three generations of LED lamps (Fig. 13)**.**

The first generation was characterized by using between 5 to 64 diodes grouped concentrically with a low radiant emittance of 50 to 300 mW / cm^2, which was not enough to achieve adequate photopolymerization [16]. Because of this, they are not currently commercially available.

The second generation managed to increase the radiant emittance that ranges between 300 and 1400 mW / cm^2 thanks to the use of higher power LEDs arranged in chips. This brought with it a decrease in the exposure time, restorations with better mechanical properties and, consequently, improved their commercialization, which is carried out to this day. In this generation, we find LCUs such as Elipar Deep Cure (3M ESPE, St. Paul, MN, USA) and Radii-cal (SDI, Victoria, Australia) [17].

The third generation arose due to the use of alternative photoinitiators such as Lucerin, Ivocerin TPO and PPD, which require light with a wavelength of less than 450 nm. Therefore, in this generation, LEDs that emit violet light were incorporated together with those that emit blue light, covering a broad spectrum of wavelengths of approximately 380-500 nm. Likewise, it was possible to reach radiant emittances above 1400 mW / cm^2. Thanks to these innovations, it was possible to take advantage of resin-based materials with alternative photoinitiators, as well as to obtain restorations with excellent mechanical properties [18]. Examples in this group are the following, Valo (Ultradent Products Inc., South Jordan, USA) (Fig. 8), Bluephase (Ivoclar Vivadent AG, Schaan, Liechtenstein), among others.

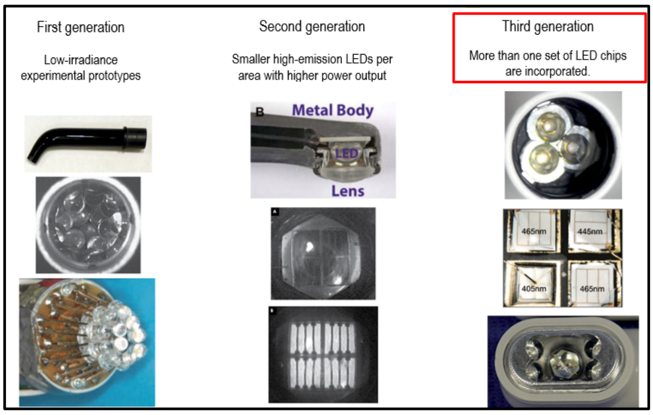


Fig. 8 Generations of LED LCUs [19]

The optical properties of LCUs regarding their avelength (nm) and the irradiance spectrum (mW / cm² / nm) are shown in Fig. 9.

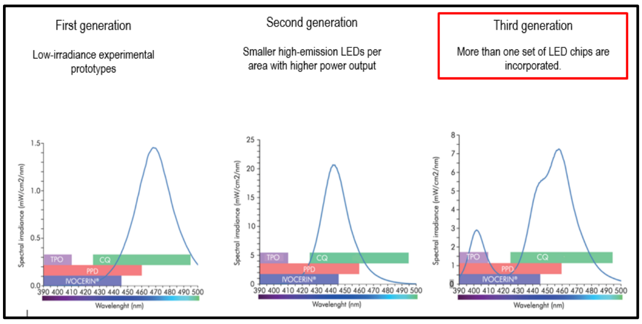


Fig. 9 Optical properties of LED lamps [19]

Resin composites

Formed from a combination of organic matrix, inorganic filler, and additional compounds, they are the material of choice for the direct restoration of teeth due to their durability and high aesthetics.

Photopolymerizable resin composites (Fig. 15) are activated by photoinitiators (the most common being camphorquinone), which stimulate the production of free radicals responsible for the initiation of polymerization [20].

Photoinitiators are activated based on two basic characteristics of light emitters [20]: the wavelength in nanometers (nm) and the light density or relation between the applied power and the surface on which it is applied (mW / cm²).

III. METHODOLOGY

Considering that the research is descriptive and explanatory and based on the study variables for the development of the proposal, the following methodology has been proposed:

1. Evaluate the **data collected from the survey applied** to professionals in the dental specialty, in order to know the problems that arise in their daily activities regarding the use of LCUs.
2. Select a **third-generation base LCU** whose technical characteristics will allow us to compare with the characteristics of the lamp in our proposal.
3. Describe the **photopolymerization** variable considering its characteristics for efficient dental treatment.
4. Describe the **LED semiconductors** variable whose characteristics will validate the proposal.
5. Present the design of the proposal, describing the type of **LED technology arrangement** that meets the requirements of efficient polymerization.

Development of the methodology

1. Analysis of data collected in the survey on the dimensions of the photopolymerization variable.

In Table V, it is observed that the sample corresponds to a total of 32 subjects of which 87.5% correspond to dentists, 6.3% to bachelors in dentistry and 6.3% to dental students, it can also be observed that more than 50% have professional experience between 3 and 5 years or more.

TABLE V
SAMPLE ACCORDING TO OCCUPATION AND EXPERIENCE

SEX	N	Occupation			Experience (years)	
		Dentist	Bachelor in Dentistry	Dentistry Student	(1, 2]	[3, 5)
Female	27	27	0	0	10	17
Male	5	1	2	2	1	4
Tot	**32**	**28**	**2**	**2**	**11**	**21**

Source:Own elaboration

From Fig. 10, it can be seen that 84.4% use LCUs to perform direct restorations (resin composite, resin-modified glass ionomer), a material for which the LCU proposal will be considered.

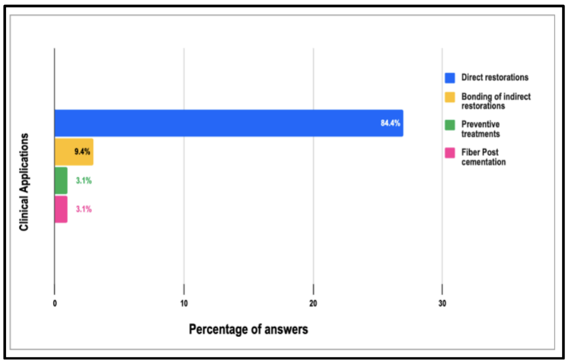


Fig. 10. Clinical applications of the LED LCUs
Source: Own elaboration

From Fig. 11, it can be seen that 37.5% responded that they use universal resins, while 34.4% stated that they use it for bulk-fill resins, and 1% for bleach resins, the latter two contain alternative photoinitiators that need of a broad spectrum light.

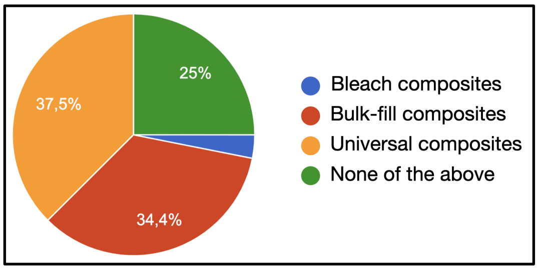


Fig. 11. Type of resin composite used apart from conventional composite.
Source: Own elaboration

In Fig. 12, it is observed that a significant 43.8% of the sample thinks that they are uncertain of having completely photocured the correct tooth surface with the current LED LCU, also 25% responded that another difficulty is the generation of temperature rise in vital teeth, as well as 15.6% considered that they have difficulty reaching posterior teeth and 6.3% indicated that they need a prolonged exposure time during polymerization.

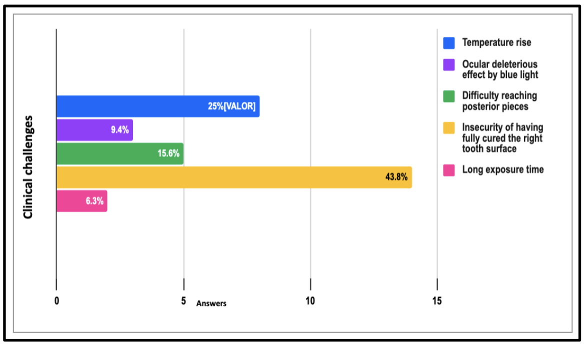


Fig. 12 Clinical challenges when using LCUs
Source: Own elaboration

In Fig. 13, it is observed that 37.5% considered the greatest disadvantage of the LED LCUs is its easy deterioration and/or fragility, followed by 28.1% who voted for costs, 18.8% for short working life of the battery and also 15.6% for design of the LCU (size, manufacturing material)

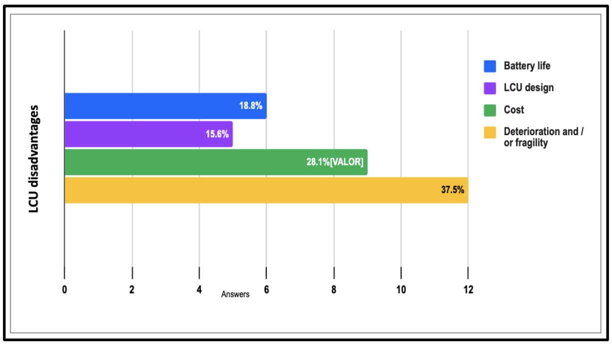


Fig. 13 Disadvantages presented by LCUs
Source: Own elaboration

Fig. 14 allowed us to obtain the exposure time for polymerization, being that 65.6% of the sample uses 20 seconds, 18.8% 40 seconds and only 15.6% 10 seconds given that most LCUs indicate that 10 seconds is enough exposure time.

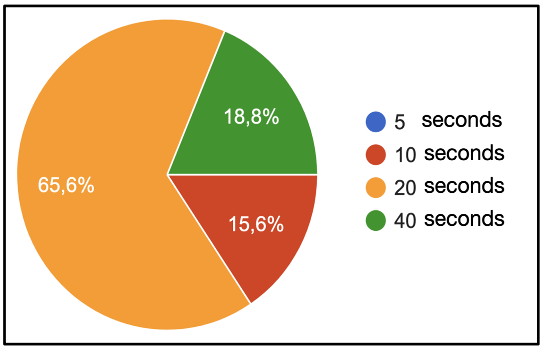


Fig. 14 Average exposure time used to photocure a 2 mm resin increment with a LED LCU radiant exposure between 1000-1600 mW / cm².
Source: Own elaboration

2. Third generation base LCU (described in the state of the art in Fig. 15).

VALO (Ultradent Products Inc., South Jordan, USA). Broad spectrum LED LCU, the body is made of aluminum; with anodized surface that resists scratches; Teflon-treated surface that repels dirt; prevents adhesion of composite; effectively dissipates heat, Table VI.

TABLE VI
MANUFACTURER INFORMATION

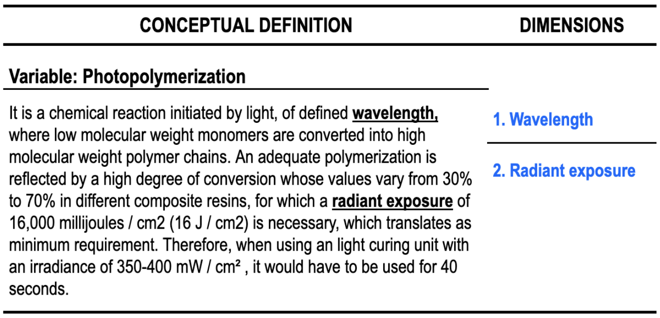
FEATURES	**VALO**
RADIANT EMITTANCE *(mW/cm²)*	**1000** (Standard) **1400** (High Power) **3200** (Xtra Power)
TIME OPTIONS (seconds)	**5, 10, 15 y 20** *(Standard)* **1, 2, 3 y 4** *(High Power)* **3** *(Xtra Power)*
LEDs	4 (blue - violet)
PEAK WAVELENGTH EMITTED	395 - 415 nm 440 - 480 nm
EMITTED WAVELENGTH RANGE	385 - 515 nm
RECOMMENDED PHOTOINICIATORS	Canforquinone, Ivocerin, Lucerin TPO, PPD
TIP DIAMETER	9,75 mm
POWER SOURCE	VALO Cordless: Rechargeable Lithium Iron Phosphate Batteries (LiFePO4). Working voltage: 3.2 VDC
CHARGER POWER SUPPLY	OUTPUT: 12 VDC at 500 mA INPUT: 100VAC to 240VAC
CHARGER	3.6VDC Lithium Iron Phosphate Smart Battery charger

Source: Own elaboration

Fig. 15 VALO LCU and power source [19]

3. Dimensions of the Photopolymerization variable for dental treatment

TABLE VII
CHARACTERIZATION OF THE VARIABLE

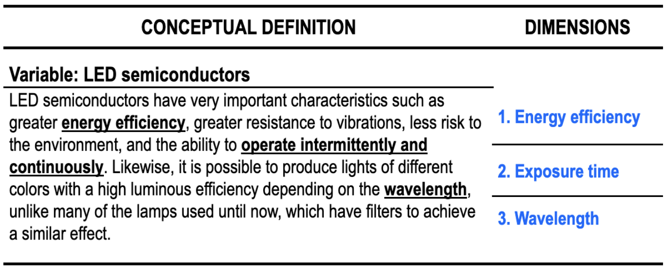


CONCEPTUAL DEFINITION	DIMENSIONS
Variable: Photopolymerization It is a chemical reaction initiated by light, of defined **wavelength,** where low molecular weight monomers are converted into high molecular weight polymer chains. An adequate polymerization is reflected by a high degree of conversion whose values vary from 30% to 70% in different composite resins, for which a **radiant exposure** of 16,000 millijoules / cm2 (16 J / cm2) is necessary, which translates as minimum requirement. Therefore, when using an light curing unit with an irradiance of 350-400 mW / cm² , it would have to be used for 40 seconds.	1. Wavelength 2. Radiant exposure

Source: [13]

4. Dimensions of the LED semiconductor variable to be considered in the proposal for the design of the polymerization lamp

TABLE VIII
CHARACTERIZATION OF THE VARIABLE



CONCEPTUAL DEFINITION	DIMENSIONS
Variable: LED semiconductors LED semiconductors have very important characteristics such as greater **energy efficiency**, greater resistance to vibrations, less risk to the environment, and the ability to **operate intermittently and continuously**. Likewise, it is possible to produce lights of different colors with a high luminous efficiency depending on the **wavelength**, unlike many of the lamps used until now, which have filters to achieve a similar effect.	1. Energy efficiency 2. Exposure time 3. Wavelength

Source: [4]

The proposal considers a third generation LCU in which LEDs that emit violet light are incorporated together with those that emit blue light, covering a wide spectrum of wavelengths of approximately 380-500 nm within the visible spectrum Fig. 16.

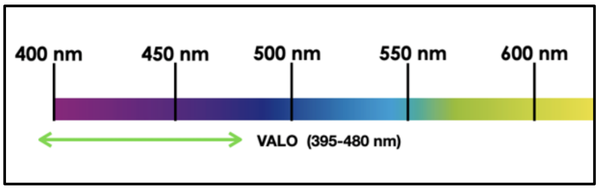


Fig. 16 Spectrum for Blue-Violet diodes

The efficiency of the LED LCU considers the following: Electrical power not greater than 30-60 milliwatts (mW), Luminous efficiency of 18-22 lumens per watt (lm / W), Flux (lm) - Flux power Luminous efficacy (LEF) (lm / W), the higher the LEF, the more efficient the luminaire will be. Color: Color temperature and color rendering index (CRI) and Photometric Distribution (Lenses or Collimators).

Due to the need to increase the brightness of the LEDs, the current levels will not be increased but instead an additional diode is used in the study LCU.

One of the most important aspects of getting a high light output from an LED is making sure it is installed in a well-designed fixture.

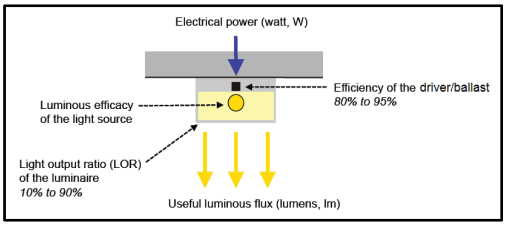


Fig. 17 Luminaire efficacy factor

5. Proposal design

The design considers photometry, thermal design and electronics-based engineering of the LED semiconductor.

Basic components

LEDs: A plate of 5 miniature Blue-Violet chips (Packing of LEDs - OSTAR LIGTHNG) in such a way that they will be arranged in a wafer, soldered in series-parallel arrangements and supported by the design of a printed plate according to the model of the LCU, Fig. 18.

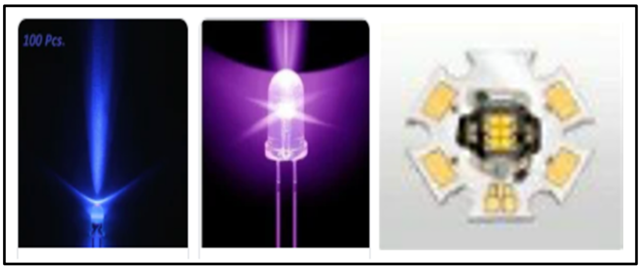


Fig. 18 Miniature set of blue and violet LEDs in a tiny surface mount (1.6x1.6x0.35mm) with details of the gold welds.

The design of the proposal is perfectly conditioned in commercial models of LCUs. The difference is that this design will allow for more efficient features.

This optical arrangement allows for improved efficiency without neglecting the high intensity light delivery required for light-induced polymerization. To do this, a conical reflector is used at the base of the light guide to ensure maximum light flux. This reflector consists of an interference-free reflective metal foil that possesses unique optical qualities, allowing optimal coupling of the light generated by the LED within the light guide.

The type of lens is very important as a light diffusing plate, the proposal recommends SOUL P5, for packing 5 chips, Fig. 19.

Fig. 19 Lente SEOUL P5 LEDs.

For optoelectronic applications, the InGaN semiconductor (which emits near-UV, green and blue light) is used. For this reason, the semiconductor material used in the manufacture of the chip is responsible for the color of the light it will emit.

Optics: The light-generated lens optical system has tight dispersion control technology that allows the optics to open up to 125°.

Driver: The LED, due to the voltage levels, requires a power supply system.

Currently, chargers are manufactured, such as those used by the VALO LCU. It is a transformer that converts AC to DC, which charges the batteries in a certain time depending on the hours of use.

Unlike a transformer, which supplies a constant voltage (the current varies depending on the electrical load), the controller maintains a constant current through the LEDs, and it is the voltage at the output of the controller that varies.

The driver also protects the LEDs from supply voltage fluctuations and occasional voltage "spikes".

The 5V and 12V LEDs are normal miniature LEDs that incorporate a series resistor for direct connection to a 5 or 12V supply.

Heat sink: The main cause of the depreciation of the luminous flux is the heat produced at the junction interface of the LED, by the light generation process. As it does not emit infrared radiation (IR), the heat produced in the light generation process must be dissipated by conduction or convection.

In the proposal it is recommended to use aluminum dissipative plates that allow the semiconductors to be cooled. It is considered part of the hardware.

The diffuser plate, the heat sinks will be placed, considering the exposure times according to the power.

IV. RESULT

This section presents the analysis of the results of the proposal based on the technical characteristics of LEDs and third-generation commercial LCUs.

The results shown will be validated when access to the laboratories of our institutions will be given, due to the pandemic in our country it is not possible to implement the prototype.

The technical data that allow the proposal to be presented are described in Table IX.

TABLE IX
TECHNICAL DATA

TERM	**UNITS**	**SYMBOL**	**DEFINITION**
Radiant Power or Radiant Flux	Watt	W	Radian energy per time unit (Joules per second)
Radiant exitance or Radiant emittance	Wat per square centimeter	mW/cm²	Radiant power (flux) emitted by a surface; e.g the tip of a LCU. Average value over area.

Source: Own elaboration

The data shown has been evaluated considering the electrical characteristics of the diodes that must be corroborated in the laboratory, in order to comply with the parameters in three dimensions: greater efficiency (radiant emittance), wavelength (visible spectrum Blue-violet) and exposure time, Table X.

TABLE X
LCU ELECTRICAL PARAMETERS

Color LED	***VIOLET***	***BLUE***	***VIOLET***	***BLUE***
Voltage (V)	2.5	2.8	3.7	4
Electric current (mA)	15	15	15	15
Quantity	5	5	5	5
Power (mW)	186	207	277.5	300
P(set) (mW)	393		577.5	
Chips	5		5	
Radiant Power (mW)	1965		2887.5	
Diameter (cm2)	0.1		0.1	
Radiant Emittance (mW/cm²))	982.5		1443.75	

Source: Own elaboration

Table XI shows the results comparing with the technical data of the VALO LCU.

TABLE XI
COMPARATIVE ELECTRICAL PARAMETERS

PARAMETERS		***PROPOSITION***	***VALO***
Voltage (V)	2.5	2.8	3.7
Radiant Emittance (mW/cm²)	Standard	982.5	1000
	High Power	1443.75	1400
Exposure time	Standard	10	5 to 20
	High Power	20	1 to 4
Wavelength (nm)	5	380-500	385-515
Diameter (mm)	1965	10	9.75

Source: Own elaboration

V. CONCLUSIONS

The background information allowed us to delimit the approach of the problem regarding the variable LED semiconductors, seeking greater efficiency in the LCUs used in daily clinical activity, covering a wide variety of dental procedures.

In the case of LED semiconductors, it was found that their application is based on their energy efficiency (low current levels) 10 to 15 mA, wavelength in the visible radioelectric spectrum (blue and violet diodes) and additionally, the working lifetime in a LCU that is approximately 10,000 hours. The LED LCU can be cordless and rechargeable, and in some cases, it can be used continuously for 65 minutes without being recharged. Its power ranges between 800 and 1400 mW/cm².

The aim was to resolve the deficiencies of the LCUs used in the dental field, based on the information collected in the research instrument, particularly in the characteristics of the generation of temperature rise (irradiance), prolonged exposure time (seconds), broad light spectrum (resin composites containing alternative photoinitiators), as well as difficulty in reaching posterior teeth (to be considered in the hardware design) and high costs.

It is important to take advantage of all the favorable properties of the interaction of the resin composite with the light emitted by the LCU to obtain the best and most complete curing of the restorative material.

ACKNOWLEDGMENT

To God because he shows us the way forward, gives us health and allows us to meet and share every day with our family, this is a privilege, in difficult times that are experienced throughout the world.

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