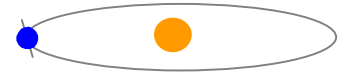


Fluid Optics™ Letter

La lettre des Sizygies



2001, December

EDITORIAL

We have the pleasure to present you the letter of the sizygies of the winter solstice in which you will find two articles : a first one on the functioning of light emitting diodes, the second on the specific heat of the water compared with specific heat of various materials.

The inventors of the Fluid Optics

MEASURES

Specific heat of the water

In the letter of the Sizygies of the spring equinox 2001, we explained the filtering of the infra-red by various filters and by notably water.

The water is an excellent infra-red filter and absorbs well the heat by radiation but it also absorbs well heat by conduction and convection.

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SUMMARY

Editorial

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Do you know the functioning of the LEDs ?

Measures

Specific heat of the water

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PRODUCTS

Do you know the functioning of the LEDs ?

New powerful light emitting diodes appeared on the market, we know the LEDs because they invaded our electronic devices (televisions, video recorders, hi-fi equipment, etc.). Do you know the functioning of the LEDs ? How are they built ? One of our subscribers has posted these kinds of questions. We try here to understand their functioning without too much entering the fine details of the physics of the solid.

Crystal structure and chemical bonds

The silicon is the king of the semiconductor electronics. More than 95 % of the electronic components are made of silicon. In a way, we can say that composed semiconductors, such as GaAs or InP, were developed to imitate and to improve the success of the silicon, at least in some niches of electronic technology.

In a crystal, atoms are combined into a periodic structure.

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In a crystal of silicon, every atom owns four valence electrons on its electronic outer shell (see figure 3) and forms a tetrahedral bond with the four nearest neighbours atoms (see figure 1). Every covalent bond between two atoms of silicon shares two electrons. In the tetrahedral bonding configuration of a crystal of silicon, every atom shares eight valence electrons with its four nearest neighbours.

Such a valence electron configuration, with height valence electrons, approximates the stable valence electron configuration of a noble gas, argon here (Ar). These covalent bonds are responsible for the creation of the silicon crystal. The silicon crystal structure, built from a face centred cubic, is type of diamond. {Miserey 1993}.

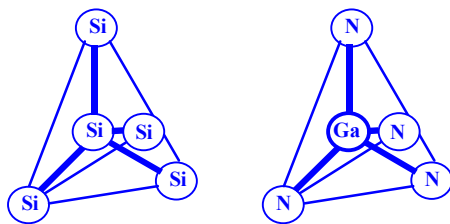


Figure 1 - Si and GaN tetrahedral bond

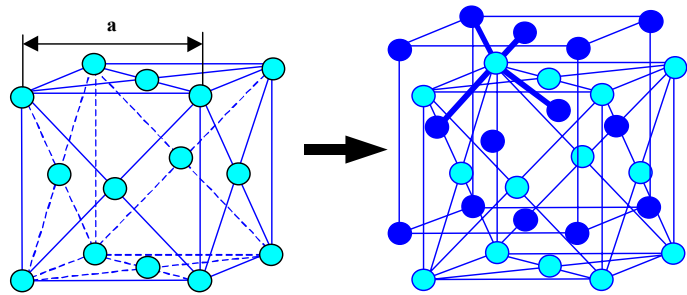


Figure 2 - Face centred cubic structure (left). "a" is the lattice constant. Diamond structure (right) built from a face centred cubic structure. Thick blue lines' show a tetrahedral bond into a diamond structure.

Current components used to create composed semiconductors are found in the columns III (B, Al, Ga, In, Tl) et V (N, P, As, Sb, Bi) of the table of periodic system of elements. The Roman numerals denoting the number of valence electrons for elements in these columns. As for silicon, we need 8 valence electrons to complete the covalent bonds between atoms to form a stable crystal. If we take for example atoms of gallium (Ga) (column III) and atoms of nitrogen (N) (colonne V), they own 3 valence electrons and 5 valence electrons respectively on their electronic outer shell (figure 3).

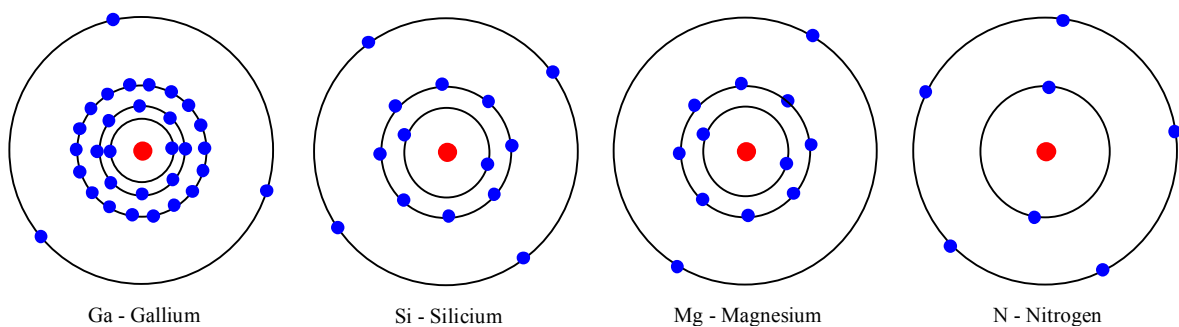


Figure 3 - Some interesting atoms and their outer shells

By sharing these electrons, we obtain 8 electrons which allow to complete the outer shell of these atoms.

This configuration allows to get closer of a stable electronic structure and to create a crystal structure.

In the case of atoms of gallium and nitogen, the crystal structure is type of *wurtzite* (see figure 6) and we find, as for silicon crystal, tetrahedral bonds (see figure 1).

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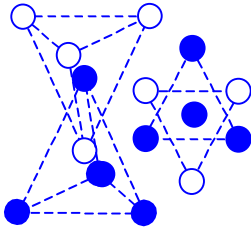


Figure 4 - Diamond type crystal structure
(Perspective and top view)

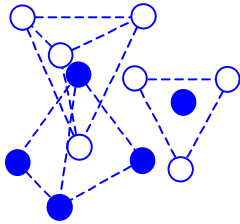


Figure 5 - Wurtzite type crystal structure
(Perspective and top view)

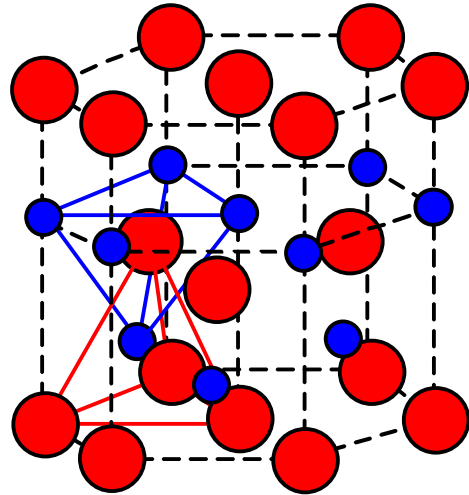


Figure 6 - GaN crystal structure of type *wurtzite*.
In red, gallium atoms.
In blue, nitrogen atoms.

To make GaN conductive to electrons (n type), we can dope it with silicon. For that, we replace a small percentage of gallium atoms with silicon atoms. As silicon has four valence electrons instead of three for gallium (voir figure 3), after filling the outer shells of the atoms, one electron remains for each silicon atom introduced. This electron is free to circulate as for a conductor. *{SU 2000}*

To make GaN conductive to holes (p type), we can dope it with magnesium. For that, we replace a small percentage of gallium atoms with magnesium atoms. As magnesium have two valence electrons instead of three for gallium (voir figure 3), after filling the outer shells of the atoms, one electron miss for each magensium atom introduced. An electron of a neighbour bond can complete this hole which will move.

Under forward bias, holes and electrons can recombine in the active region to create light (see figure 7).

If we add Al and In to GaN, we form a quaternary composed semiconductor AlInGaN. We can adjust the gap to choose the wavelength. If we match the lattice constant with the one of the substrate, we obtain a better light efficiency. *{SU 2000}*

LED physical principle

In LEDs, holes and electrons recombine in a double heterostucture or quantum well active region when they pass through a “pn” junction of a doped semiconductor under a forward bias. The small gap active layer is placed between two big gap confinement layers *{Hincelin 1993}*. This same structure can be used for laser diodes, since a LED is only a laser diode without cavity.

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Most of the LEDs of weak power, that we find commonly, are composed of a GaAsP crystal built on a GaAs substrate. These crystals have a lattice constant not well matched with their substrate, which doesn't produce luminous LEDs. So, the efficiency depends on the matching of the lattice constant of the crystal with the lattice constant of the substrate. The more these lattice constants match, the higher the efficiency is. {SU 2000}

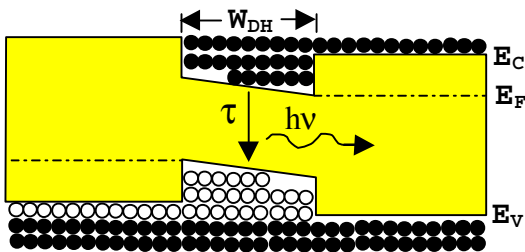


Figure 7 - Heterojunction under a forward bias {Hincelin 1993}. Today, most powerful LEDs are conceived on a double heterostructure where the carriers are confined in the active region (W_{DH}).

E_C = conduction band energy

E_V = valence band energy

E_F = Fermi energy (the energy at which probability that a quantum state is occupied by an electron is 1/2).

τ is the spontaneous recombination lifetime

gap : $E_G = E_C - E_V$

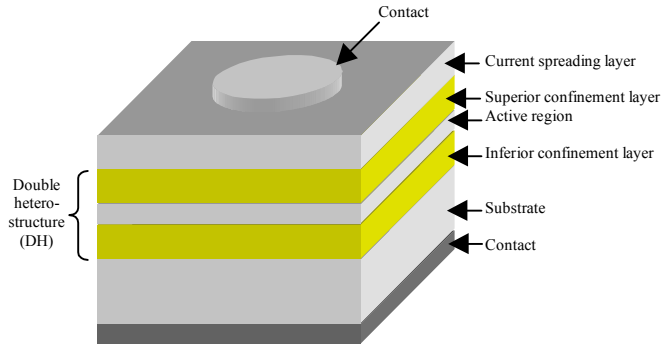


Figure 8 - Example of a LED structure with a double heterostructure where the active region can be AlGaInP with two confinement layers AlInP and the current spreading layer AlGaAs. The substrate is GaAs.

The LED breakthrough was thanks to the introduction of quaternary composed semiconductors AlGaInP for the red and yellow, and GaN materials for the blue and the green. AlGaInP, used as an active region of a double heterostructure or quantum well structure, built on a GaAs substrate, is highly luminous. The range of gaps, from 1.9 to 2.2 eV, corresponds to the range of wavelength from 650 to 570 nm and can vary by mixing Al and Ga atoms in the AlGaInP structure. For GaN material, one can mix GaN, which emits in the ultraviolet, with InN, which emits in the red, to form InGaN, which emits any color from ultraviolet to the red. This variation of colour depends on the the rate of Ga atoms compared to In atoms in the InGaN structure. {SU 2000}

Commercialized LEDs characteristics

These very luminous LEDs promise to be a new white light source. The traditional LEDs have very small powers, few milliwatts, but today LEDs based on AlInGaP have accomplished records in laboratory of 100 lumens in the ambre colour. The most powerful commercialized LEDs which we have found comes from Luxeon. {Luxeon Emitter 2001} (see next table)

Colour	Wavelength or colour temperature	Luminous flux (lm) typical value (minimum)	Emission Angle(*) (°)	Internal structure	Lens geometry
White	5500 K	18 (13.9)	110	InGaN	Low dome
Green	530 nm	25 (13.9)	110	InGaN	
Cyan	505 nm	30 (13.9)	110	InGaN	
Blue	470 nm	5 (3.8)	110	InGaN	
Royal blue	455 nm	4 (1.7)	110	InGaN	
Red	625 nm	25 (13.9)	110	AlInGaP	
Amber	590 nm	20 (10.7)	110	AlInGaP	
Red	627 nm	44 (30.6)	160	AlInGaP	High dome (hemispherical)
Red -Orange	617 nm	55 (39.8)	160	AlInGaP	
Amber	590 nm	36 (23.5)	160	AlInGaP	

Table of the commercialized emitters available at LUXEON company

We notice that the most powerful LEDs are LEDs based on AlInGaP but especially those whose used an hemispherical output lens (high dome). These two types of LEDs used different shapes of chips. The low dome LED is based on a rectangular chip with a transparent substrate while the high dome LED is based on a truncated inverted pyramid chip. This different chip shape allows to catch 1,5 time more light. {Craford 2001}

Conclusion

We have explained, how LEDs generate light, how the optimisation of the chip internal structure allows to raise the light efficiency (lattice constant match, type of material). We have less exposed the details on the geometric shape of the chip. This subject could be treated on a future sisygies letter.

Craford 2001 M. George Craford - Recent progress of LEDs for lighting - Lumileds - Presentation at Opto 2001 exhibition - Electronic document available at <http://www.lumileds.com> - (Oct. 2001)

Hincelin 1993 G. Hincelin - Optoélectronique - Polycopié Cours B1 - CNAM/MEDIA - p52 à p64 & p166 à 169 - (1993 -1994)

Luxeon Emitter 2001 Luxeon - Technical Data Luxeon Emitter - Electronic document available at <http://www.luxeon.com> - p3 - (Dec. 2001)

Miserey 1993 F. Miserey - Physique du solide - Polycopié Cours B1 - CNAM/MEDIA - p5 à 9 & p16 à p19 & p92 et p93 & p105 à p107 - (1993-1994)

SU 2000 Frederick Su - Revolutionizing light : LEDs, ELDs and OLEDs - SPIE (Dec. 2000)

(Continuation of page 1)

The capacities of cooling of fluids based on the water are recognized for a very long time because one finds it today in the radiators of all our cars to cool engines.

Thermal properties of the water and its big transparency to the visible radiation make it an excellent environment for optics. It seems possible, by adapting the composition of the fluid based on water, to increase its capacities of filtering the radiation to adapt it more to the answer curve of the eye.

In dynamic fluid optics, the fluid is used to filter the infra-red energy. We can also use, by an adequate circulation, the fluid for cooling the optical whole system which is confined in a small space little-aerated or not aerated.

It is not the case for the solid filters which filter radiation by absorption because they are consisted in glass main part.

If we look to the specific heat of the material in the table below then we find that the specific heat of glass is weak. (Specific heat is the capacity of the material to absorb heat by unity of mass).

Material	C (J.kg ⁻¹ .K ⁻¹)	Material	C (J.kg ⁻¹ .K ⁻¹)
Water	4,2.10 ³	Aluminium	0,9.10 ³
Ice	2,1.10 ³	Stainless steel	0,5.10 ³
Water vapor	1,9.10 ³	Iron	0,7.10 ³
Air	1.10 ³	Glass	0,8.10 ³

This specific heat is even inferior to the specific heat of air. The water presents the best specific heat of the table which is five times more important than specific heat of the glass.

NEWS

If there is a subject you wish to see treated in this letter, you can directly contact us by email at the address:

syzygies@optique-fluide.org

You can also join MEGALUX, the company charged to exploit Fluid Optics at the address:

info@megalux.com

NEXT LETTER

The next Letter of the Syzygies will appear for the spring equinox, end of march.