Why Edge-Emitting Diode Lasers are Better Light Sources for Hair Removal?

1. Overview

Edge-Emitting Diode Lasers (EELs) have the technical advantages of high power density, high efficiency and high beam uniformity; it has shown high reliability under high temperature operation in long term, and it offers mature products with various wavelength options.

This paper discusses the technical features of EELs with experimental data, and compares EELs with VCSELs. It concludes that EELs is more suitable for aesthetic and medical applications such as hair removal compared with VCSELs; VCSELs has more advantages in applications such as data communications, 3D imaging, and etc.

2. Principles of laser Hair Removal

Laser hair removal targets the entire hair structure, meeting the principle of selective photothermolysis. Light energy with a specific wavelength is primarily absorbed by the endogenous chromospheres melanin resulting in rapid heating which is required for local thermal necrosis of the follicles' regenerative structures.

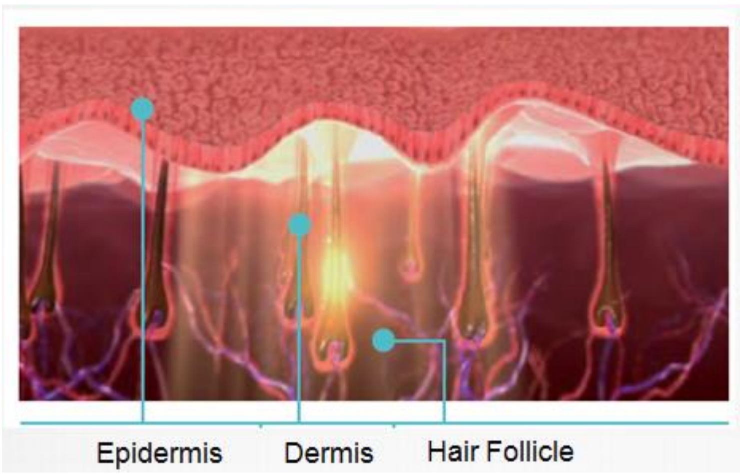


Fig. 1 Scheme of hair structure

To achieve complete destruction of hair follicle, the laser system must be able to deliver high energy fluence in a very short period of time. Laser energy is absorbed by melanin which is rich in hair follicle and then converted into heat, the heat makes the hair follicle quickly rise to high temperature, thus destroy the follicle and prevent hair regeneration [1]. Therefore, the laser with high power density and short pulse width is the best technical solution to achieve permanent hair removal.

3. Typical laser hair removal configurations

Many leading laser equipment manufacturers are adopting high peak power technologies for their hair removal machines, including LightSheer product from Lumenis, which is considered the "gold standard" in the industry.

1）Lumenis LightSheer DUET[2]

The LightSheer Duet hair removal system includes two heads, the LightSheer ET Classic handpiece and HS Vacuum handpiece. Lightsheer ET hand piece has a spot size of 9mm*9mm, and the energy density is adjustable within the range of 10~100J / cm^2. Lightsheer HS handpiece has a spot size of 22mm*35mm, and it’s often used for rapid hair removal for large areas such as limbs and back, and its energy density can be adjusted in the range of 4.5~12J / cm^2.

Fig.2 LightSheer Duet Hair Removal System

Specifications

PLATFORM	LightSheer DUET	
HANDPIECE	ET	HS
Technical Specifications		
Laser Type	AlGaAs Diode Arrays	AlGaAs Diode Arrays
Wavelength	805 nm (nominal)	805 nm (nominal)
Spot Size	9 x 9 mm	22 x 35 mm
Repetition rate	Up to 3 Hz	Up to 3 Hz
Pulse Repetitions	1 pulse	1 – 3 pulses
Fluence	10 - 100 J/cm^2	4.5 - 12 J/cm^2
Pulse Width (OptiPulse™)	5 - 400 ms	30 - 400 ms
Peak Power	1620 W	2310 W
Comfort Management	ChillTip™ contact cooling (5ºC)	Vacuum-Assist (up to 18 inHg)
Preset Parameters	Yes	Yes
Warranty	1 Year	1 Year
On-Site Service	Yes; replaceable handpiece	Yes; replaceable handpiece

Fig.3 Specifications of LightSheer Duet

2）Asclepion MeDioStar NeXT pro[3]

MeDioStar NeXT pro system is manufactured by German manufacturer Asclepion; it features a combination of multiple wavelengths including 810nm and 940nm. With a spot size of 9.1cm^2, it offers the largest spot size in the market. The laser power is rated at 2400W, and the maximum energy density is 20J / cm^2.

Fig.4 Asclepion MeDioStar NeXT pro

TECHNICAL SPECIFICATIONS

Device Laser	MeDioStar NeXT PRO High Power Diode Laser, class 4	Spot size	9.1, 3.0, 1.4 or 1.0 cm² (hair removal)* 0.12 cm² (vascular treatments)
Power	max. 2400 W	Frequency	max. 12 Hz*
Wavelength	755 – 950 nm*	Pulse length	6 – 400 ms*
Fluence	max. 20 J/cm² (XL-L Handpiece) max. 60 J/cm² (XL-S Handpiece) max. 35 J/cm² (ALX Handpiece) max. 47 J/cm² (STANDARD Handpiece) max. 90 J/cm² (HIGH POWER Handpiece) max. 210 J/cm² (VASCULAR Handpiece)	Display	8.4" LCD
		Sizes	Table Top: 36.5 x 56 x 46.5 cm With Trolley: 36.5 x 56 x 93 cm
		Weight	ca. 35 kg

Fig.5 Specifications of Asclepion MeDioStar NeXT pro

4. Technical Features of EELs

1). Power density

Power density is the most important parameter for hair removal applications. Power density of Edge-emitting diode lasers can reach up to 1200W / cm^2.

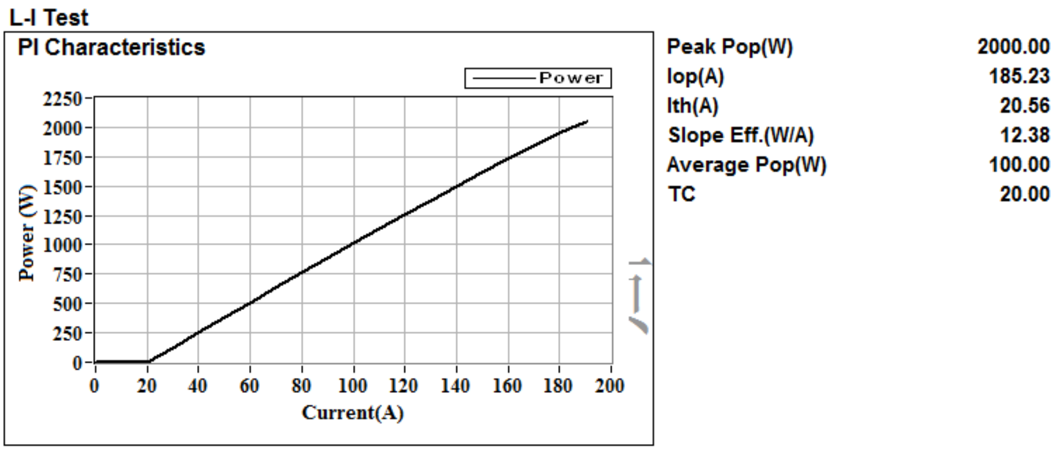
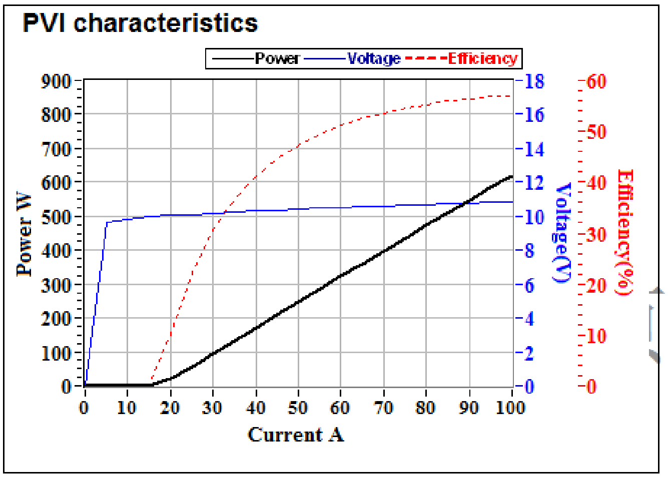


Fig.6 PI characteristics of 2000W EELs (spot size: 1.68cm^2)

2) Wall-plug efficiency

Wall-plug efficiency of edge-emitting diode laser at 808nm can reach up to 57%.



Pop(W)	600.00
Iop(A)	97.44
Ith(A)	17.49
Slope Eff.(W/A)	7.57
Eff.@Iop(%)	56.85
Max Eff.(%)	56.98
Rs(mOhms)	10.18
V @Iop(V)	10.83
TC	25.00

Fig.7 PVI characteristics of 600W EELs

3) Beam Uniformity

The beam uniformity of Edge-emitting diode laser can be more than 90% after the light travels through a light guide.

Fig.8 Beam profile on a thermal paper

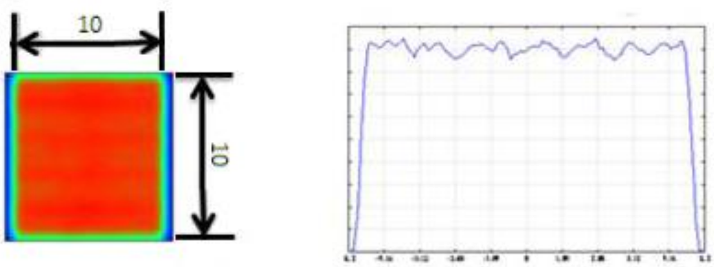


Fig.9 Modeling of a 10x10mm² EELs spot

4) High Temperature Operation

EELs usually work at 25℃ -30℃. AuSn packaged EELs diode lasers can work reliably for more than 20 million shots at 60℃.

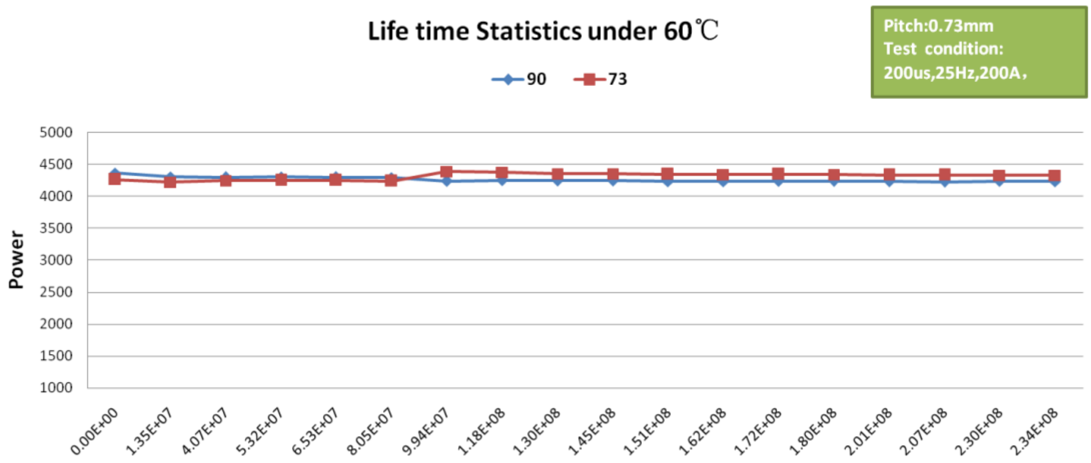


Fig.10 Lifetime Statistics under 60℃

5) Long Lifetime

Results show that lifetime of EELs exceeded 10,000 hours or 100 Million shots, and it can meet requirements of different applications such as medical, industrial application and consumer electronics.

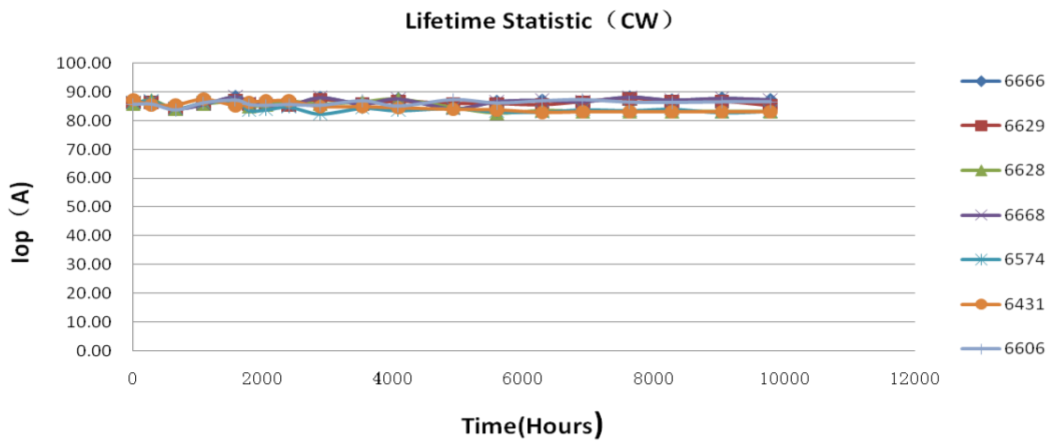


Fig.11 Lifetime Statistics of EELs (CW)

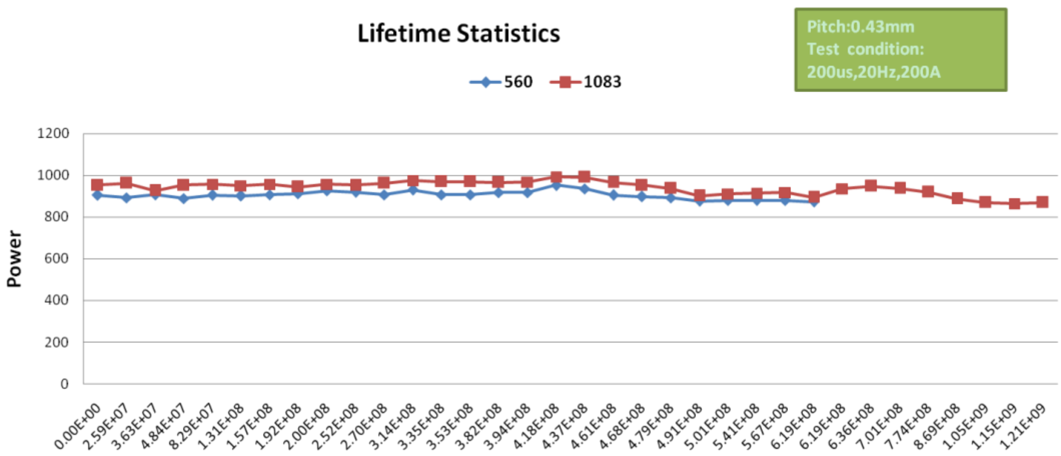


Fig.12 Lifetime Statistics of EELs (200 μ s,20Hz)

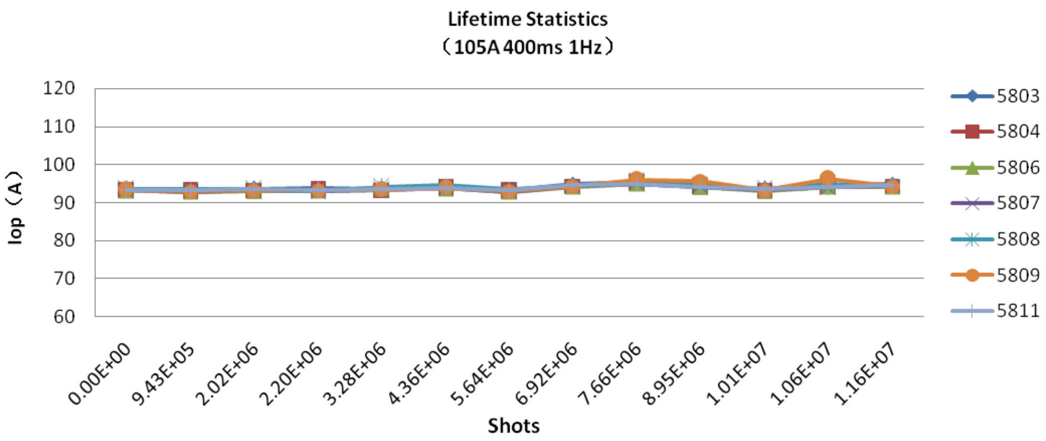


Fig.13 Lifetime Statistics of EELs (400ms, 1Hz)

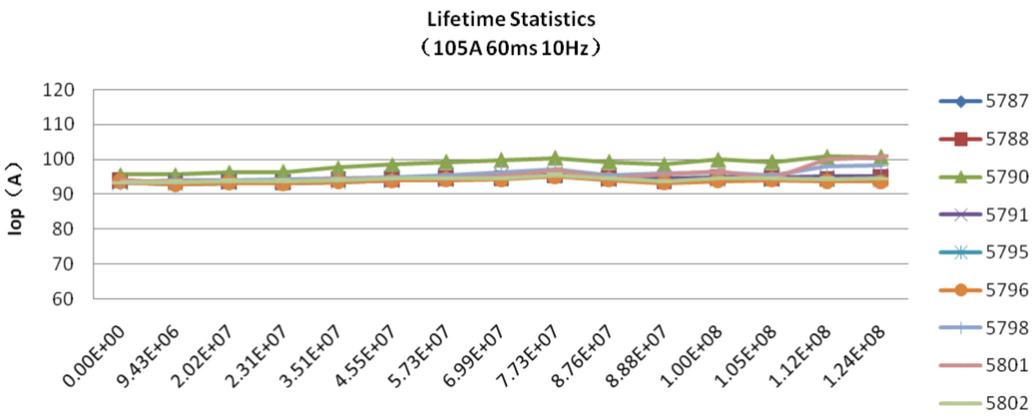


Fig.14 Lifetime Statistics of EELs (60ms, 10Hz)

6) Various wavelength options

Various wavelengths of EELs are available for hair removal application.

(a) (b) (c)

Fig.15 Alma Soprano offers hand pieces at different wavelengths [4].

(a) 755nm; (b) 1064nm; (c) 810nm

5. VCSELs in comparison with EELs

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a relatively recent type of semiconductor lasers which were first invented in the mid-1980's [5].Within the first two years of commercial availability (1996), VCSELs became the technology of choice for short range data communication and local area networks[6]. This success was mainly due to the VCSEL's high-speed digital modulation and high reliability. However, VCSELs have been confined to low-power applications because of its low power density.

In comparison with EEL, VCSELs' advantages are:

1) Wavelength stability: The lasing wavelength in a VCSEL is very stable, since it is fixed by the short (1~1.5 wavelength thick) Fabry-Perot cavity.

2) Wavelength uniformity & spectral width: Growth technology has improved such that VCSEL 3" wafers are produced with less than a 2nm standard deviation for the cavity wavelength. This allows for the fabrication of VCSEL 2-D arrays with little wavelength variation between the elements of the array (<1nm full-width half maximum spectral width).

3) Reliability: Because VCSELs are not subject to catastrophic optical damage (COD) because the gain region is embedded in the epi-structure and does not interact with the emission surface. Because of these, the reliability of VCSELS can be higher than EELs. Typical FIT values (failures in one billion device-hours) for VCSELs are <10.)

On the other hand, VCSELs' disadvantages are:

1) Lower power density:

Low power density is the major technical defects of VCSELs.

2) Lower wall-plug efficiency

The wall-plug efficiency of VCSELs is between 30% and 40%，which is much lower than EELs (over 50%).

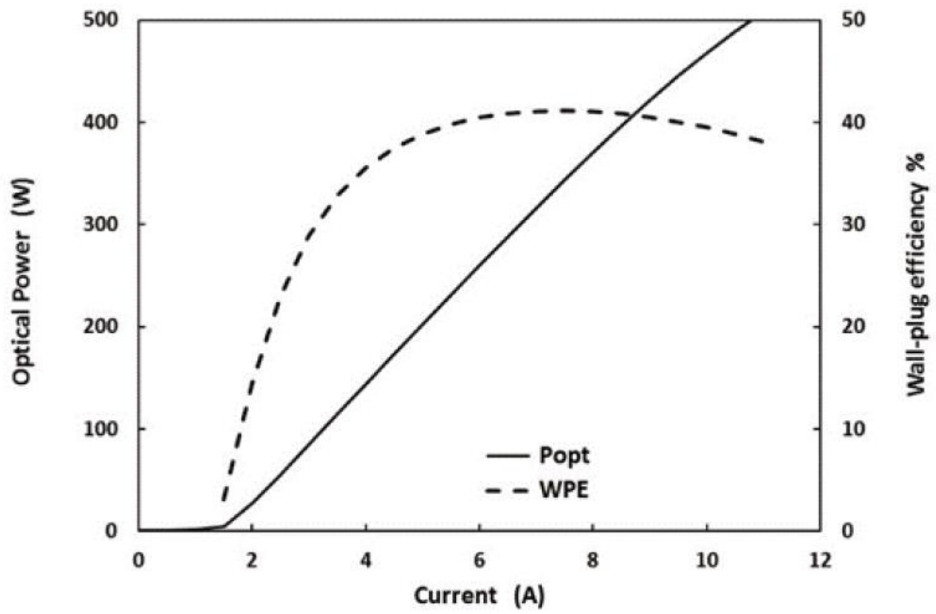


Fig.16 Output power and efficiency vs. current for a VCSEL[7].

3) Compromised beam uniformity:

The emitting surface of VCSELs forms an electrical connected two-dimensional array. The large gaps between different emitting surfaces affect the overall beam uniformity.

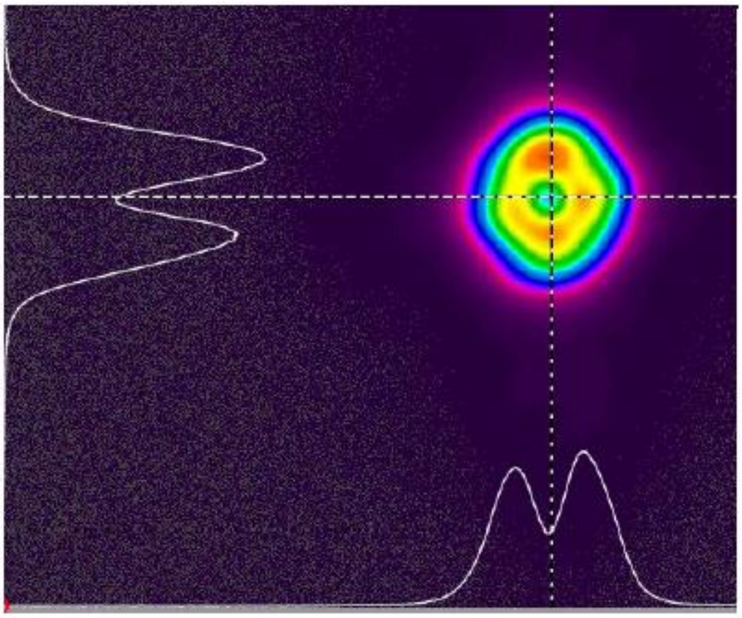


Fig. 17 Measurement of the far-field EEL of a 2x2mm² VCSEL chip with integrated micro-lenses and of the optical power at two different positions of the detector [7].

4) Dramatic Power Decrease at Higher Operating Temperature

Temperature	Power(45A)	Peak Wavelength(nm)	Centroid Wavelength(nm)	FWHM (nm)	FW90% (nm)
20C	41.31W	808.82	808.87	0.7	1.4
30C	39.90W	809.57	809.59	0.7	1.39
40C	38.56W	810.09	810.09	0.72	1.43
50C	36.9W	810.67	810.67	0.72	1.38
60C	33.44W	811.43	811.35	0.74	1.44

The most important parameters for hair removal applications include power density, beam uniformity, and wall-plug efficiency. Wavelength uniformity and spectral width are not so critical because the absorption of light by melanin decreases lowly with the increase of wavelength.

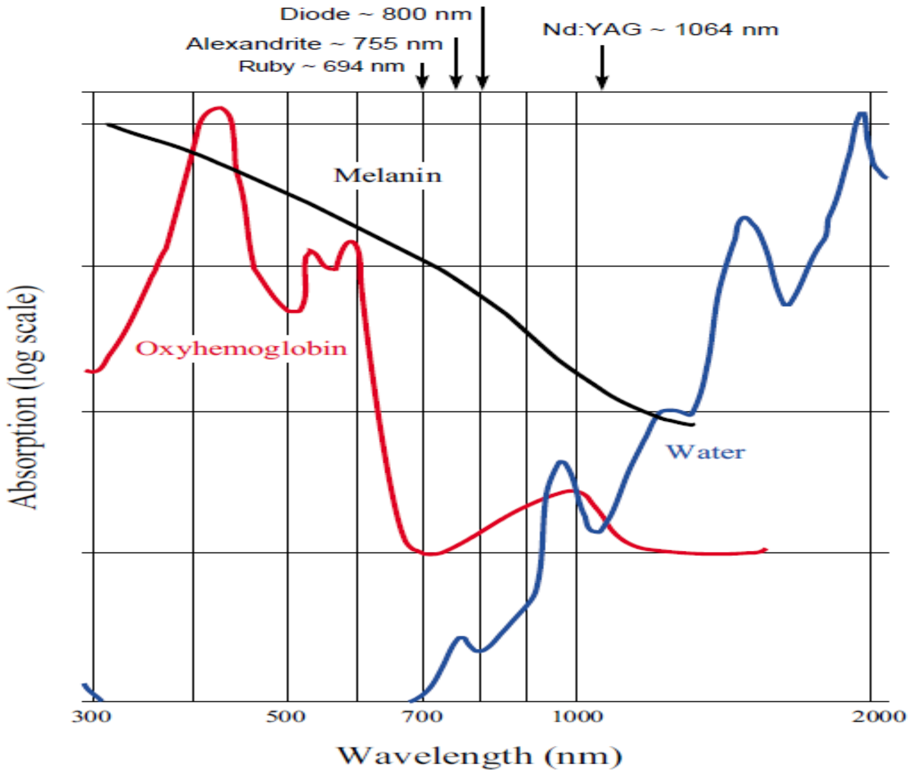


Fig.18 Wavelength dependence of absorption coefficient of Melanin

	EELs	**VCSELs**
Power Density	>1660W/cm^2 in emission area	160--1000W/cm^2 in emission area
Beam Uniformity	>90% after light guide	Low uniformity, hard to be homogenized
Wall-plug Efficiency	50%-60%	30%-40%
Wavelength Variety	500nm-1600nm	800nm-1100nm
Applications	Medical and aesthetic; Infrared illumination; Pumping; Metal processing	3D imaging ; Datacom; Wearable sensors; LIDARs

To summarize, EELs is more suitable for laser hair removal and VCSELs on the other hand, is good for applications such as data communication and 3D imaging.

5. References:

[1] Gan S D, Graber E M. Laser Hair Removal: A Review[J]. Dermatologic Surgery, 2013, 39(6):823-838.

[2] http://www.lumenis.com/Solutions/Aesthetic/LightSheer-DUET2/

[3] http://www.asclepion.com/asclepion_product/mediostar-next-pro/

[4] https://www.almalasers.com/alma-products/soprano-ice-2/

[5] Ikyo A B, Marko I P, HiEEL K, et al. Temperature stable mid-infrared GaInAsSb/GaSb Vertical Cavity Surface Emitting Lasers (VCSELs)[J]. Scientific Reports, 2016, 6(40):19595.

[6] Henini M. Developments continue for VCSEL research[J]. III-Vs Review, 2000, 13(1):18-23.

[7] Moench H, Conrads R, Gronenborn S, et al. Integrated high power VCSEL systems[C]// SPIE LASE. 2016:97330V.