structure (MQW) comprising quantum dots. According to this publication, the MQW structure can be used to produce a phosphor free red and white nitride based LED. This document is also cited here as reference.

The prior art has considerable disadvantages. The prior art fluorescence tubes, LEDs and phosphor arrangements do not allow sufficiently high resolution tuning of the emission spectra. Furthermore the prior art fluorescence tubes, LEDs and phosphor arrangements are very poor as the primary source of light for the plants, yielding poor quality harvests in dark growth cavities, such as basements of buildings etc.

The prior art MQW and quantum dot illumination devices are mainly focused on replacement of disadvantageous architectural features (such as phosphorus), which is of little help to a horticulturalist.

Quite clearly more sophisticated plant cultivation technologies are needed to combat global hunger in the developing countries, as well as to reduce the environmental impact of food and plant production in the developed world.

SUMMARY

Embodiments of t~~T~~he invention are~~under study is~~ directed towards a system and a method for effectively realising a quantum confined semiconductor illumination device that addresses the photomorphogenetic needs of plants with better precision than ever before.

In an embodiment~~one aspect~~ of the invention the quantum confinement is realised as a quantum dot, i.e. confinement in all 3-spatial dimensions, or indeed as a plurality of quantum dots. Besides using quantum dots, quantum wires (2-D spatial confinement) and quantum wells (1-D spatial confinement) can be used to implement the invention in some embodiments, for example by replacing one or more quantum dots from said embodiments.

According to an embodiment~~one aspect~~ of the invention, a quantum dot –light emitting diode features quantum dots of different sizes. In quantum dots the size inversely correlates with the emission energy, i.e. smaller quantum dots emit higher energies. In an embodiment~~one aspect~~ of the invention the size distribution of quantum dots is selected so that it produces an aggregate emission spectrum with favourable photomorphogenetic effects for the plants that are being cultivated with the artificial light emitted by said quantum dot –light emitting diode of the invention.

Embodiments~~It is an aim~~ of the present invention seek to eliminate at least a part of the problems relating to the art and to provide a new way of facilitating plant growth using quantum dots.

Embodiments~~It is a first objective~~ of the invention seek to provide a single light emission source based quantum dot device to which the photosynthesis process responds well.

Embodiments~~It is a second objective~~ of the invention seek to provide a lighting fixture for greenhouse cultivation based on a photosynthesis photon flux (PPF) optimized quantum dot device.

Embodiments~~It is a third objective~~ of the invention seek to achieve a quantum dot device that provides at least two emission peaks in the wavelength range from 300 to 800 nm and at least one of the emission peaks has Full width at half maximum (FWHM) of at least 50 nm or more.

Embodiments~~It is a fourth objective~~ of the invention seek to provide a quantum dot based greenhouse cultivation lighting fixture wherein the emission intensity ratio of two emission frequencies, 300–500 nm and 600–800 nm, are reduced with less than 20 % during the 10,000 hours of operation.

Embodiments~~It is a fifth objective~~ of the invention seek to provide a technical solution giving a better PPF value per Watt (i.e. PPFs against used power wattage) than attained by a conventional high pressure sodium or LED lamp normally used in greenhouse

cultivation and thus providing an energy efficient light source for greenhouse cultivation process and artificial lighting used therein.

Embodiments~~It is a sixth objective~~ of the invention seek to provide a single light emission source wherein the emission at a frequency of 300–500 nm is generated by the semiconductor quantum dot chip and the emission at a frequency of 600–800 nm is generated using another quantum dot chip. The inventor has discovered that for example cucumber and lettuce plants reach greater length and/or mass when illuminated with the inventive horticultural light that includes far red light (700-800 nm).

Embodiments~~It is a seventh objective~~ of the invention seek to provide a single light emission source where the emission at frequency of 300–500 nm is generated by the semiconductor quantum dot chip and the emission at frequency of 600–800 nm is generated using a second quantum dot chip, which is either driven by electric current for light emission, or operates as an wavelength up-converter of the earlier quantum dot. The wavelength up-conversion to produce 600–800 nm radiation is achieved by using one or more wavelength up-conversion quantum dots in proximity of the first quantum dot emission source.

In this application "up-conversion" is construed as changing the wavelength of incoming absorbed light to emitted light of longer wavelengths.

Embodiments~~It is an eighth objective~~ of the invention seek to provide 400–500 nm, 600–800 nm or both frequency ranges partial or complete wavelength up-conversion of semiconductor quantum dot chip radiation, the chip having emission at 300–500 nm range emission range. The wavelength up-conversion is realized by using either organic, inorganic or combination of both types of materials.

Embodiments~~It is a ninth objective~~ of the invention seek to provide the wavelength up-conversion using nano-sized particle material for the up-conversion.

Embodiments~~It is a tenth objective~~ of the invention seek to provide the wavelength up-conversion using molecular like material for the up-conversion.

Embodiments~~It is an eleventh objective~~ of the invention seek to provide the wavelength up-conversion using a polymeric material wherein the up-conversion material is covalently bonded to the polymer matrix providing the wavelength up-conversion.

Embodiments~~It is a twelfth objective~~ of the invention seek to present a quantum dot based lighting fixture where the spectral band 500-600 nm is suppressed. In this suppressed band there is hardly any or no emission at all, or in any case less emission than in either of the adjacent bands 400-500 nm, 600-700 nm. The suppression can be achieved in accordance with the invention by not having any or only a small amount of primary emission in the band 400-500 nm, and by making sure that any up-conversion causes a wavelength shift that shifts the wavelength beyond 600 nm. It is generally known that green plants cannot utilize green light (500-600 nm) radiation as well as the radiation in the adjacent bands, as this radiation merely reflects from the plant rather than is being absorbed for photosynthetic conversion.

Embodiments~~It is a thirteenth objective~~ of the invention seek to present a quantum dot based lighting fixture that maximizes anabolic growth of plants by providing desired far-red light, whereas it minimizes green light which from the perspective of plant cultivation is radiation that wastes energy. This ~~objective~~ is realized in an embodiment~~one aspect~~ of the invention by a blue quantum dot light emitter with a wavelength up-conversion device which up-converts part of the emitted blue light (300-500) nm into a broad red spectrum component (600-800nm) which has a far-red component, but omits and/or minimizes the green component (500-600nm).

Embodiments of t~~T~~he present invention seek to provides a quantum dot and a related light fixture suitable for greenhouse cultivation. According to an embodiment~~the invention~~, the quantum dot has a specific emission frequency pattern, viz. it has at least two spectral characteristics; one emission peak with a full width at half maximum of at least 50 nm or more and having a peak wavelength in the range of 600 to 700 nm, and a second spectral characteristics

having a peak wavelength below 500 nm range. The emission peaks of the quantum dots match well with a plant photosynthesis response spectrum and is therefore particularly suitable for high efficiency artificial lighting.

Some or all of the aforementioned advantages of embodiments of the invention are accrued with a quantum dot size distribution that optimises the emission spectrum for the said photomorphogenetic variable affected, which can be any of the following biological parameters: weight, leaf number, root mass, stem height, chemical composition (such as vitamin, mineral, and/or nutrient content and/or concentration) the plant has at different time points or at harvesting maturity.

According to a first aspect, there is provided a~~A lighting device for~~ plant cultivation lighting device, wherein~~is in accordance with the invention and characterised in that~~ said lighting device comprises a plurality of quantum dots of different size producing light for plant cultivation.

A lighting method for plant cultivation is in accordance with an embodiment~~the invention~~ and wherein~~characterised in that~~ light is produced by a plurality of quantum dots of different size and said light illuminates at least one plant.

A greenhouse and/or growth chamber light device is in accordance with an embodiment~~the invention~~ and wherein~~characterised in that~~ said light device comprises at least one quantum dot.

A horticultural lighting fixture in accordance with an embodiment~~the invention~~ comprises at least one quantum dot having

a) first spectral characteristics including a peak in the wavelength range from 600 to 700 nm and arranged to exhibit a full width at half maximum of at least 50 nm or more;

b) second spectral characteristics with a maximum of 50 nm full width at half maximum and arranged to exhibit a peak wavelength in the range from 440 to 500 nm, and optionally

c) all or part of the emission at a frequency of 600–800 nm is generated using a whole or partial wavelength up-conversion of the quantum dot chip radiation power and/or by another electrically powered quantum dot.

A horticultural lighting fixture in accordance with an embodiment~~the invention~~ comprises at least one quantum dot having

a) first spectral characteristics including a peak in the wavelength range from 600 to 700 nm and arranged to exhibit a full width at half maximum of at least 50 nm or more;

b) second spectral characteristics with a maximum of 50 nm full width at half maximum and arranged to exhibit a peak wavelength in the range from 440 to 500 nm, and

c) at least a part or the whole of the emission at wavelengths of 500–600 nm is arranged to be minimized and/or omitted and/or to be reduced below the intensity in 400-500 nm band and below the intensity in 600-700 nm band.

Use of the lighting device or fixture of any of the five preceding paragraphs is in accordance with an embodiment~~the invention~~ in providing light for at least one plant with the said at least one plant in ambient light or in a dark cavity with said lighting device or fixture as the sole source of light. Similarly a method for enhancing plant growth of the five preceding paragraphs is in accordance with an embodiment~~the invention~~ wherein at least one lighting device or fixture emits light to at least one plant with the said at least one plant in ambient light or in a dark cavity with said lighting device or fixture as the sole source of light.

According to a second aspect, there is provided a light emitting component of a horticultural light~~is in accordance with the invention and~~ comprisinges;

- a light emitting quantum dot semiconductor chip; and
- a light wavelength up-conversion quantum dot which is deposited in direct proximity of the quantum dot chip;

said component being capable of emitting two characteristic light emission peaks, and

at least a part or the whole of the emission at wavelengths of 500–600 nm is arranged to be minimized and/or omitted and/or to be reduced below the intensity in 400-500 nm band and below the intensity in 600-700 nm band.

Use of the light emitting component of the preceding paragraph, is in accordance with a third aspect of the invention, in providing light for at least one plant with the said at least one plant in ambient light or in a dark cavity with said lighting device or fixture as the sole source of light. Similarly ~~a~~, methods for enhancing plant growth, are~~is~~ in accordance with ~~the~~further aspects of the invention, wherein at least one light emitting component of the preceding paragraph emits light to at least one plant with the said at least one plant in ambient light or in a dark cavity with said lighting device or fixture as the sole source of light.

A horticultural lighting fixture in a dark or shaded cavity is in accordance with an embodiment~~the invention~~ and comprises at least one LED having

a) first spectral characteristics including a peak in the wavelength range from 600 to 700 nm and arranged to exhibit a full width at half maximum of at least 50 nm or more;

b) second spectral characteristics with a maximum of 50 nm full width at half maximum and arranged to exhibit a peak wavelength in the range from 440 to 500 nm, and

c) all or part of the emission at a frequency of 600–800 nm is generated using a whole or partial wavelength up-conversion of the LED chip radiation power.

A horticultural lighting fixture in a dark or shaded cavity is in accordance with an embodiment~~the invention~~ and comprises at least one LED having

a) first spectral characteristics including a peak in the wavelength range from 600 to 700 nm and arranged to exhibit a full width at half maximum of at least 50 nm or more;

b) second spectral characteristics with a maximum of 50 nm full width at half maximum and arranged to exhibit a peak wavelength in the range from 440 to 500 nm, and

c) at least a part or the whole of the emission at wavelengths of 500–600 nm is arranged to be minimized and/or omitted and/or to be reduced below the intensity in 400-500 nm band and below the intensity in 600-700 nm band.

The quantum dot and/or LED based implementations may~~of the invention~~ allow very fine spectral tuning of the emission spectrum, and therefore very good energy efficiency and improved photomorphogenetic control in plant cultivation relying on artificial light. This advantage is even more pronounced when using quantum dots only, as the spectral tuning provided by them is superior to conventional LEDs. Furthermore, the quality of the harvests is considerably improved with the light devices of the invention and this brings a multitude of advantages related to cultivation in dark growth chambers or chambers with very limited ambient light: Firstly plants may be grown closer to the site of consumption, e.g. in residential basements in big cities, thereby eliminating transportation costs. Secondly, plants may be grown in geographies where agriculture is not traditionally possible, e.g. hot desert conditions in the summer. Thirdly, as the quality of the plants is improved also the consistency between individual plants is improved which makes harvesting easier. This is because there are less rejected individuals and machine vision based harvesting equipment can recognize the plants better when they have a consistent quality, size and colour. Fourthly, the properties of the plants may be varied in a controlled fashion because nearly all growth parameters are under control, which is especially advantageous when cultivating flowers and ornamental plants. Fifthly, a constant photon dose everyday for the plants assists in the administration of nutrients, as the nutrient dose can be maintained the same year round. Sixthly, in very hot and sunny geographies plants may be grown in dark opaque growth chambers that reflect sunlight. The energy spent in the artificial illumination of the invention is considerably less than what would have been expended in air conditioning or cooling the plant under sunlight.

It should be noted that a dark cavity is construed as a light constrained space that has zero or low levels of sunlight and/or ambient light without the artificial light source of the invention emitting photons, but the said cavity can be of any size, microscopically