Increasing the external quantum efficiency of yellow-green LEDs.

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Abstract:

LEDs, long finding their application only as indicator lights, finally find a place in more common use as high-tech automobile lights. Not only do these excellent devices have extremely long life, but the lack of moving parts or a vacuum (such as that in an incandescent bulb) means that they could be used in many ways that fluorescent and incandescent lights never could. This paper briefly explains these possibilities and then explores a potential solution to one of the many obstacles facing widespread acceptance of LEDs as a general source of lighting. The blue-tint thought to be characteristic of white LEDs gives them a cold feeling that the public would not accept for use in their homes; this problem can be overcome by more completely developing LEDs that emit light in the yellow-green part of the spectrum.

Introduction:

Light: symbol of clarity and knowledge, victor over fear and hate. Festivals are built around it, deities clothe themselves in it, and a certain university's spiritual center was designed for it. Humans see nothing but light. Yet the development of convenient artificial lighting sources is relatively new for humans. For thousands of years, the only source of light was some sort of flame. Not until Thomas Edison invented the incandescent light bulb in 1879 did mankind start using artificial lights commonly. Now, in cities, the night looks nearly like the day.

Still, many problems exist with these lighting sources. Incandescent bulbs, especially, are known to be energy hogs. They, like their flame predecessors, are based on the idea of heating something up so that it emits light as the excited electrons cool back down. Most of the energy used in this process is dissipated simply as heat, instead of being turned into light.

Enter the Light Emitting Diode. Revolutionary lighting devices that work off of injection electroluminescence rather than heat, transferring electrical energy directly to electron potential energy. Whereas with the best current lighting sources, fluorescent lights, the maximum efficiency achievable is 28% by the simple physics of how the devices work, the maximum achievable efficiency of LEDs could reach 100%. Currently they struggle to compete with fluorescent lights for efficiency, but they are in the early stages of development, whereas fluorescent lights have all but reached their limit.

Most essential to LEDs making their way into the general illumination market is the quality of the light. Efficiency and cost of LEDs has continued to sink, but there remain concerns with the quality of the light produced.

Two methods exist for creating white light with LEDs: the use of a phosphor in conjunction with the LED, the same sort of phosphor that is used in a fluorescent light; and a

combination of differently colored LEDs. The first method limits not only the efficiency of the device, requiring that additional conversions between energy types happen rather than one simple electricity-to-light conversion taking place, but lacks also the extreme functionality of the second approach. With the polychromatic technique, wherein two to five monochromatic LEDs are mixed to give white, there exist possibilities never dreamed of with prior lighting techniques. Lights can be mixed differently to give multiple colors of lights, lighting can be adjusted for the environment or person, light-color-quality can be traded off for efficiency, and so on. As LEDs are solid-state devices, no precautions must be taken with them such as those taken with their bulb-laden ancestors. LEDs could eventually find their way into previously unthought-of places, such as clothing and furniture.

The two most efficient LEDs are made with AlInGaN and AlInGaP. The nitride-based LEDs are the heavy-hitters of the blue region, the phosphates dominate the reds. Both of them slack off a bit in the yellow and green area. This is especially problematic because humans are most perceptive of this yellow-green region and it is the region most prevalent in sunlight. For a lighting source to be accepted for general use, it needs to be a good producer of yellow light.

Efficiency in LEDs can mean a lot of things. In this case, it is both the external quantum efficiency and the luminous efficiencies that these two particular LEDs excel in. In general, the two go together. This paper will concern itself with the external quantum efficiency, which is the product of the number of photons created in the LED (internal quantum efficiency) and the number of photons that make it out of the material (light extraction efficiency).

This paper looks at experimentation aimed at improving the material quality of AlInGaN. Whereas AlInGaP fails at producing yellow light due to inherent features of its composition,

AlInGaN becomes a poor-producer of yellow due to poorer quality of the material. This paper looks at two methods of improving the quality of this substance.

First, the possibility of matching the AlInGaN with a better substrate is looked at. The goal of this approach is to increase the light-extraction efficiency and therefore the external quantum efficiency. Three different substrates are tested; a test-diode is constructed using each of the three and they are compared to a commercially available AlInGaN yellow LED.

Second, the possibility of doping AlInGaN with another element is looked into. Computer simulations are set up using four different doping materials. After finding the most appropriate substance, methods of producing this improved AlInGaP are discussed.

With the proposed modifications to AlInGaN, a 50% increase in the external quantum efficiency of yellow-green LEDs should be achievable. This improvement makes polychromatic LED white-light sources cheaper to make and more efficient. Whereas with the previous substances and techniques the only acceptable quality of white light was achievable with four or five monochromatic LED sources, a usable quality of light seems achievable with only three. These numbers are discussed in the closing of the document.

Literature Review

When Henry Joseph Round stumbled upon LEDs in 1907—about twenty years before quantum mechanics was able to attempt to explain them—he understandably had no idea what caused the light. In his letter to the editors of Electric World in February of that year, he stated that about half of silicon carbide crystals would emit yellow light when a potential of ten volts was applied across them. He also noted that when a voltage of one hundred ten was applied, a large percentage of the samples would glow, though not only yellow this time, but also orange, green, or blue. His letter was sent to ask if anyone else knew what might cause the light; his best guess was that the current heated the silicon dioxide, producing light by the only known process at the time: thermoluminescence (Shur 2005). In 1907, the world still exclaimed at the wonder of Thomas Edison's incandescent light bulb, no one cared at all about the inefficiencies of the process. Round's newly discovered light was far too dim for any practical use, and the physics of the time could not explain what happened. Round's inquiry to other scientists seems to have gone unanswered for at least fifteen years, and the discovery of a brand new process, electro-luminescence, was not noticed by most of the world (Steigerwald 2002).

Electroluminescence was not … [the rest is deleted to meet space requirements]