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THE IMPACT OF LED LIGHTING ON REDUCING ENERGY CONSUMPTION COSTS

The global LED lighting market is projected to reach $168.87 billion by 2030, growing at a CAGR of 11.0% from 2023 to 2030 [1]. The segment covering automotive, general, architectural, agricultural applications together with displays is the key growth driver of the market. The cost of LED semiconductor devices, in turn, is closely tied to the cost of their manufacturing processes.

Similar to Moore's law, which describes the development of integrated circuits, the progress of LED technology is described by Haitz's law. Both laws reflect the trends in the optimization of semiconductor manufacturing processes. Haitz's logarithmic dependence is usually presented as the total luminous flux per packaged LED over time, which is duplicated by the dependence of the cost per lumen. According to this dependence, the white LED efficiency was expected to reach 100 lm/W by 2010, with a forecast of doubling every decade after that. In 2024, a new white single-chip LED was introduced with a luminous flux of 199 lm/W and a luminosity of 746 lumens. This achievement illustrates the general trend of improving LED efficiency, which is consistent with Haitz's law. However, these days Haitz's law does not describe the trend of technological progress development in full. The reason for this is that the efficiency of light conversion depends on many factors, such as optimal heat dissipation and design features of quantum-dimensional structures. At the same time, the law takes only single-crystal devices into account, while certain devices available on the market incorporate multiple LEDs within a single package. Therefore, for a better assessment of the efficiency of the LED luminous flux, it is necessary to take into account additional factors. In addition to the epitaxial growth process, the LED manufacturing process includes the stages of phosphor application and packaging, which also form the price of the final semiconductor device. And, while the cost of applying the phosphor and packaging remains practically unchanged, the cost of one LED can be reduced by using precision systems for controlling the growth of LED structures [2, 3] and using substrates of a larger diameter. Moreover, this approach correlates with current trends towards the implementation of intellectually-oriented approaches to managing the costs of industrial producers, which allows for a significant increase in their economic efficiency [4, p. 250].

To qualitatively evaluate the progress of LED technology and forecast future energy efficiency trends, Haitz's law necessitates considering additional factors. The cost of the final LED device is largely determined by the costs of the epitaxial growth process, which is characterized by high competition and a limited number of equipment manufacturers, which creates oligopolistic barriers. As a result, further improvement of the energy efficiency of LED lighting requires significant capital investments in the technological development of epitaxial growth technology for complex semiconductors.

References:

1. The flaws in Haitz's law. *Compound Semiconductor*. 2024. URL: https://compoundsemiconductor.net/article/114102/The_flaws_in_Haitz%E2%80%99s_law?lm/W

2. A. Voronko, D. Novikov, and O. Shymanovskyi, "Temperature Drift of Silicon Photodiode Spectral Sensitivity," *Radioelectronics and Communications Systems*, vol. 66, is. 2, pp. 74–84, 2023. DOI: https://doi.org/10.3103/S073527272302005X.

3. A. Voronko, "Specifics of designing an infrared pyrometer-reflectometer for semiconductor heterostructure fabrication", Bull. Kyiv Polytech. Inst. Ser. Instrum. Mak., no. 67(1), pp. 25–30, Jun. 2024. DOI: https://doi.org/10.20535/1970.67(1).2024.306723

4. Tulchynska S. O., Solosich. O. S. Intellectual economy as an imperative for the development of systems for ensuring the economic security of economic entities. *Економічний вісник Державного вищого навчального закладу «Український державний хіміко-технологічний університет»*. 2023. №1. С. 247-257. DOI: https://doi.org/10.32434/2415-3974-2022-17-1-247-257.