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Inertial Fusion Energy’s Role in Developing the Market for High Power Laser Diodes

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Abstract: Production-cost models for high-power laser-diodes indicate systems of 10GW peak power coupled with facilitization of semi-conductor manufacturing capacity could yield costs below $0.02/Watt. This is sufficient to make IFE competitive with other nuclear power technologies.

OCIS codes: Diode laser arrays (140.2010); Lasers, diode-pumped (1430.3480); Fusion (350.2660)

1. Introduction

Demonstration of fusion ignition and gain on the National Ignition Facility will open the possibility of using inertial confinement fusion to create a clean and inexhaustible source of electric power. Demonstration of inertial fusion energy (IFE) at a plant scale could be accomplished with a few-Hertz, megajoule-class, diode-pumped solid-state laser (DPSSL). The feasibility of DPSSLs as drivers for practical, cost competitive IFE power plants is strongly dependent on the cost of high power laser diodes [1], and will require a reduction of cost by at least two orders of magnitude below current prices of $3-$5 / peak Watt fully packaged.

With improvements in high power diode performance, durability and manufacturing the challenge today is to develop a market volume that can provide the quantities needed to achieve the required reduction in cost. The DPSSLs for IFE will require ~10 GW of high power laser diodes per plant, or several orders of magnitude greater than the existing market [2]. For a GigaWatt-class IFE power plant, the cost for diodes alone at today’s prices will exceed the price tag of the entire power plant by anywhere from 10 up to 20 times. If diode costs were $0.02/W the diode costs for the plant would be only 5%-10% of the total power plant cost, and the cost of electricity would be in the range of 6 ¢/kWeh [3].

In the late1990s studies [4], were conducted to predict diode costs, but the high power laser diode industry was not mature enough to accurately ascertain how much it would cost to automate and facilitize fabrication capacity for large quantities of high peak power diodes. Today, the industry fabrication technology has matured and there are more applicable diode array architectures available: stacks of >200 Watt edge-emitting diode bars [5], or wafer-scale monolithic diode arrays, such as the Vertical Cavity Surface Emitting Lasers (VCSELs) [6]. Many of the fabrication tools for mass-producing diode lasers are now available to make cost effective high power diode lasers.

Today’s production methods are very labor intensive. Using cost models that rely on facilitization, automation, and market forces, credible laser diode bar costs can approach $0.02/W to $0.04/W unpackaged. However, wafer-scale diode arrays such as VCSELs could potentially be significantly cheaper due to their high power densities and potential for large scale automated processing (Fig. 1).

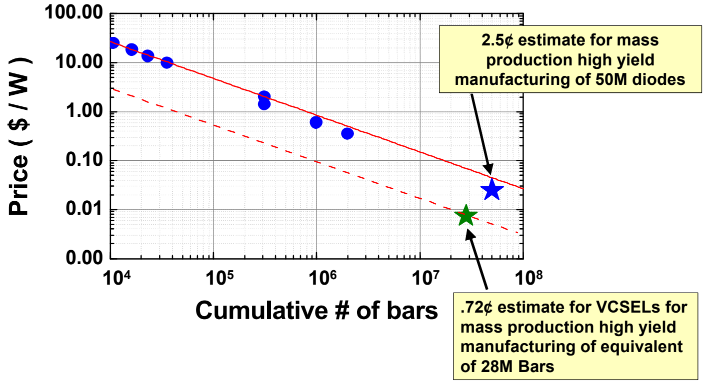

Fig. 1 Diode cost scaling model based on historical worldwide diode prices

2. Model for Diode Production

Modeling costs for semi-conductor fabrication identified cost drivers for diode laser production. With the model discussed here we examined high power laser diode costs for various production rates and scales of production, comparing costs for a large, or a small foundry.

Tracking and comparing the processing steps shown in Figure 2 indicates large cost savings by eliminating, or reconfiguring some of the steps. Significant cost reduction would be achieved by keeping much of the high power diode fabrication at the wafer-scale. Figure 3 illustrates how wafer processing of VCSEL diodes eliminates the need for cleaving and facet coating. Cost savings are also realized by testing earlier in the process flow, which should increase yield. Finally, the "packaging" step for diode bars involves significant handling and soldering of bars to the substrate of the "package", while in the case of VCSEL's, the wafer itself becomes the package with only nominal metallization and contacting of the entire wafer to a heatsink.

The cost model includes material costs, production rates, manpower costs, capital costs recovery of a production line, and the facility and utility costs to support the system. Production parameters for the model were solicited from manufacturers, including e.g. expected yields and processing rates.

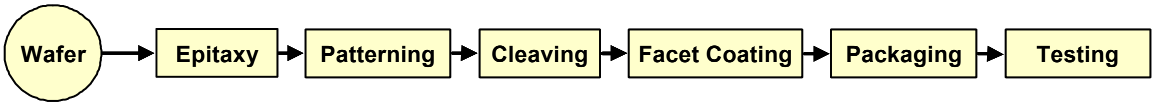

Fig. 2 Process flow for discrete edge-emitting diode bars.

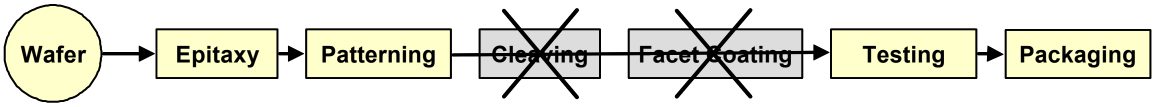

Fig. 3 Process flow for wafer-scale diodes eliminates cleaving and facet coating and facilitates early wafer-scale testing.

3. High Power Diode Costs

Our results have shown a significant cost advantage to processing wafer-scale 2-D diode arrays. Until now most learning curve cost projections were based on high power diode bar processing. Modeling production for wafer-scale 2-D diode arrays, such as VCSEL diodes has generated a new, significantly lower cost learning curve for IFE.

Packaging and power conditioning of high power diodes are also big cost drivers and can double, or triple the final packaged and power conditioned cost per peak Watt for a diode array. These items were modeled separately, but the cost reductions for VCSELs are also realized for packaging and power conditioning.

Further optimization of the model is required and we will continue to consult with the high power laser diode industry, but our preliminary results have shown that < $.02/Watt peak is feasible.

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