Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 3S (2016) S165 – S170

Proceedings of the International Conference on Diamond and Carbon Materials

On efficiency of power diode lasers using diamond heat sinks

V.V. Parashchuk

Stepanov Institute of Physics, Academy of Sciences of Belarus,
Independence Ave. 68, Minsk 220072, Belarus
E-mail: v_shchuka@rambler.ru
Tel. +375172841341, Fax.+375172840879

Abstract

We have developed a process for producing high-adhesion metallic coatings which enables the fabrication of laser diode (LDs) structures with improved performance parameters on highly effective natural and synthetic diamond heat sinks (DHS). The mounting of CW laser diodes on DHS by a non-optimized process increases their power output by up to a factor of 2, considerably extends the linear (working) field of their power current characteristic and increases their slope efficiency by a factor of 1.5 - 2 relative to that of LDs on copper heat sinks. Optimization of the mounting process increases the slope efficiency only in the case of copper bases. The use of diamond heat sink bases extends the drive current range of pulsed diode bars by a factor of 2 - 3 and enables them to operate at more than one order of magnitude longer pump pulse durations (up to milliseconds) when the pulse repetition rate exceeds 10 Hz.

Selection and Peer-review under responsibility of the chairs of the International Conference on Diamond and Carbon Materials 2014.

Keywords: high-power diode lasers; thermal processes; diamond heat sink substrates; high-adhesion metallization; laser fabrication technology; output characteristics.

---

1. Introduction

Laser diodes (LDs) and diode bars having output powers from a few to tens and hundreds of watts require effective heat removal from the active region of the semiconductor heterostructure. It was shown as early as the late 1960s [1] that diamond crystals can be employed as effective heat sink bases for semiconductor lasers. The thermal conductivity of diamond is one of its most remarkable properties. It exceeds by several folds the thermal

Selection and Peer-review under responsibility of the chairs of the International Conference on Diamond and Carbon Materials 2014.
doi:10.1016/j.matpr.2016.02.028

conductivity of all other solid materials: metals, semiconductors and dielectrics [2], including copper, which is used most frequently to remove heat in electronics. Diamond is also applied as a highly effective heat sink material in other semiconductor devices, such as avalanche and Gunn diodes [1, 3, 4]. The use of diamond in commercial applications is however limited by its relatively high cost and a number of technical problems.

In this work, with the aim of solving these problems we analyze the possibility of using synthetic and natural, single-crystal and polycrystalline diamond and its thermal performance. The advantages of diamond as a heat sink material manifest themselves only when its thermal resistance R_{th} exceeds that of all other components of the device [1]. As will be shown below, this can be achieved by using a new approach to the moralization of diamond heat sink bases (DHSs), which ensures sufficiently good and uniform adhesion of the metallic coating, and by developing an appropriate mounting process for diode structures.

Super hard materials, including diamond, are composed of atoms in stable electronic configurations and are non-reactive with most metals and solders. Adequate adhesion to diamond might be offered by metals that have high chemical affinity for carbon, preferably those that form carbides possessing metallic bonding and metallic properties (chromium, titanium, niobium, zirconium, tantalum, molybdenum and tungsten). The development of a process for applying high-adhesion metallic coatings to diamond is an important practical issue, which is far from being resolved.

According to previous data [5, 6], the thermal performance of a DHS depends not only on the good adhesion of its metallic coating but also on the electrical conductance of the coating, which should be high enough that Joule heating of the base is insignificant. These conditions are however difficult to meet simultaneously because the desired adhesion strength can be achieved at a coating thickness $d \leq 0.1\ \mu$m, whereas good electrical conductance is ensured by $d > 0.1\ \mu$m. Moreover, an important requirement is uniform adhesion to the main surfaces of the base: mounting surface, backside and lateral sides (which ensure electrical connection between the first two surfaces at the minimum resistivity of the metallic coating). The results of our early experiments indicate that chemical deposition of nickel ensures the best adhesion of the DHS's coating compared to other deposition processes but fails to ensure the desired uniformity. This was interpreted in terms of the difference in physical properties between the surfaces in question and the growth features of the crystals used. Subsequently, the deposition process was modified by introducing additional surface treatment steps (cleaning and activation) and successfully applied to cubic boron nitride (c-BN), a diamond analogue attractive for our purposes. Issues pertaining to the application of c-BN and DHS's and the advantages and drawbacks of the two structures will be addressed separately.

In this paper, we examine the possibility and fundamental aspects of the metallization of heat sinks from natural and synthetic (single-crystal and polycrystalline) diamond via deposition of three-layer (Ti-Ni-Ni, Ti-Al-Ni and Cr-Ni-Ni) coatings by different techniques. Ti-Ni-Ni was used as a model system to establish conditions for the preparation of uniform, high-adhesion metallic coatings on a diamond base with the required low resistivity relative to all exposed surfaces. Similar results were obtained in the other systems. DHS's were metallized as follows: First, a Ti underlayer was grown on diamond by low-pressure plasma deposition from a charge-separated plasma, followed by chemical deposition of a Ni layer from an electrolyte solution. Next, Ni was deposited by ion beam (or magnetron) sputtering until the coating had the desired thickness. These techniques were used to develop a mounting process for diode lasers and bars. The best results were obtained when metallic coatings on the components of laser structures were produced by ion beam sputtering.

2. Growth of metallic coatings on diamond heat sinks and laser mounting process

The vacuum processes developed by us for producing metallic coatings firmly adherent to various surfaces take advantage of multifunctional ion beam and magnetron sputtering systems and employ interstitial alloys with high affinity for carbon as adhesive layers [5]. In particular, Ti/Ni films were grown by ion beam sputtering at a pressure of $7.8{\cdot}10^{-2}$ Pa in a Leybold-Heraeus Z-400 system with oil-free pumping. The diamond base was preheated to 200-350^{0}C. Metallization was performed using a purpose-designed sputtering system, which allowed surface treatment with an about 1 keV argon ion beam prior to film growth. This treatment was intended to remove the contamination and low-cohesion, disturbed layer from the diamond surface and ensured adequate adhesion of the metallic coating, at the bond energy level. The thickness of the titanium films was ~ 20 nm (deposition rate, 0.2-0.25 nm/s^{-1}) and that of the nickel films was about 300 nm (deposition rate, 0.35 nm/s^{-1}).