Semiconductor disk laser with a semiconductor-dielectric-metal mirror

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Abstract—We present optically pumped semiconductor disk lasers with a thin dielectric layer placed between the semiconductor distributed Bragg reflector and the metallization interface. The thin dielectric layer is shown to introduce negligible penalty to the thermal resistance of the device while allowing high reflectivity with a reduced number of distributed Bragg reflector layer pairs.

Keywords—Optically pumped semiconductor disk laser, distributed Bragg reflector

Optically pumped semiconductor disk lasers (SDL) offer a unique combination of high power, good beam quality and wavelength versatility. Typically, the distributed Bragg reflector (DBR) section of SDLs provides a reflectivity over 99.8 % at the signal wavelength. The number of DBR layer pairs needed to achieve the required reflectivity depends on the refractive index contrast between available materials. High refractive index contrast can be obtained using silicon and dielectric layers [1], but the high thermal resistance of these materials could limit the SDL performance. Therefore, the DBR usually comprises 20 - 40 layer pairs of semiconductor materials with relatively high thermal conductivities. An Au layer can be used to enhance the DBR reflectivity and therefore enable a lower number of DBR layer pairs [2], but the high residual pump absorption in the Ti/Cr adhesion layer could still limit the performance of these devices as shown in Ref. [3].

An alternative method for reducing the number of DBR layer pairs is to use a thin dielectric layer between the semiconductor DBR and the metallization interface [4]. This approach avoids the highly absorbing Ti/Cr adhesion layer and allows a lower number of DBR layer pairs as compared to a semiconductor-metal mirror design. Appropriate choices for the thin dielectric and metal layers are Al₂O₃ and ~ 90 % reflective Al, because they offer a combination of high adhesion and suppressed material diffusion between the layers of the assembly. Such an approach is particularly promising for material systems operating above the 1 µm band that employ thick thermally insulating DBRs. However, even for GaAs-based SDLs emitting in the 1 µm spectral region, the design allows thinner DBRs with reduced strain and misfit dislocation density, the elimination of highly pump-absorbing metal layers, and increased residual pump reflection for double-band DBRs and resonant pumping schemes.

The studied SDLs were designed to operate at 1050 nm. The active region comprised 13 GaInAs quantum wells (QWs) and the DBR 28.5 pairs quarter-wave thick GaAs/AlAs layers. The wafer was cut into pieces from which different numbers of DBR layer pairs were removed by wet etching. 90 nm of Al₂O₃ was then deposited by atomic layer deposition (ALD) on the topmost GaAs surfaces, followed by 120 nm of Al. As a reference, an SDL with the full 28.5 DBR layer pairs and a metallization comprising 15 nm Ti and 120 nm Al was fabricated. A schematic of the SDL is shown Fig. 1. The experimental results together with numerical simulations confirm that the Al₂O₃/Al design enhances the DBR reflectivity while introducing negligible penalty to the thermal resistance of the device.

\[ \text{HR mirror, } R > 99.8\% \]
\[ \text{RoC} = 200 \text{ mm} \]

\[ \begin{align*}
\text{Active region with} & \\
13 \text{InGaAs QWs} & \\
\text{GaAs/AlAs DBR} & \\
\text{with 11.5 / 18.5 / 28.5 layer pairs} & \\
120 \text{ nm Al} & \\
90 \text{ nm Al}_2\text{O}_3 / 15 \text{ nm Ti} & \\
\end{align*} \]

Fig. 1. Schematic of the semiconductor disk laser cavity. The details of the SDL chips are shown on the right.

References