

Electrically Injected Thin-film InGaAsP Microdisk Lasers Integrated on a Si-wafer

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We report on electrically pumped lasing in a microdisk cavity defined in an InGaAsP-based thin film bonded on top of a silicon wafer. The top metal contact is placed in the centre of the disk, whereas the bottom contacting is done by means of a thin lateral contacting layer. In order to avoid large optical absorption in p-type contact layers, a tunnel junction was used in combination with two n-type contacts. Lasing was observed in pulsed regime with a current threshold as low as 0.55mA, for microdisks with a diameter of 6 μ m.

Introduction

Microdisk lasers have attracted a lot of interest lately, mostly due to their potential role as very compact light sources with low power consumption in large scale photonic integrated circuits. Several authors have reported electrically injected lasing in microdisk structures supported by a pedestal, some with lasing thresholds well

below 100 μ A [1]-[3]. Our work focuses on the integration of these III-V microdisk

lasers on a Si platform. This approach not only facilitates integration with silicon electronics but also with silicon photonics. Indeed, because of the transparency of Si at the telecommunications wavelengths, and the fact that CMOS technology can be used in the fabrication of photonic components in Silicon-on-Insulator (SOI) [4], silicon has emerged as a promising platform for photonic functions. In our approach, integration of compact active optoelectronic components on a silicon platform is done by bonding a thin III-V film on top of it. Optically pumped lasing in microdisk lasers integrated on a Si-wafer and their optical coupling to an underlying SOI-waveguide has already been demonstrated [5]. In this paper we report on electrically pumped devices.

Design aspects

An important design aspect of electrically injected, thin-film laser devices is the epilayer heterostructure composition: this should allow efficient carrier injection while preserving optical resonance quality (see figure 1). An important issue is how to contact

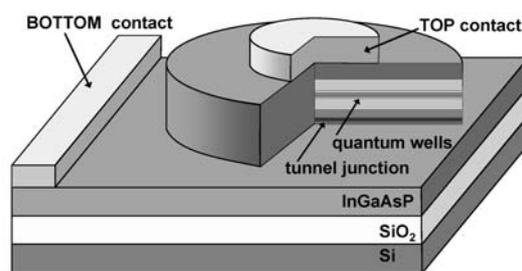


Figure 1. Microdisk laser design

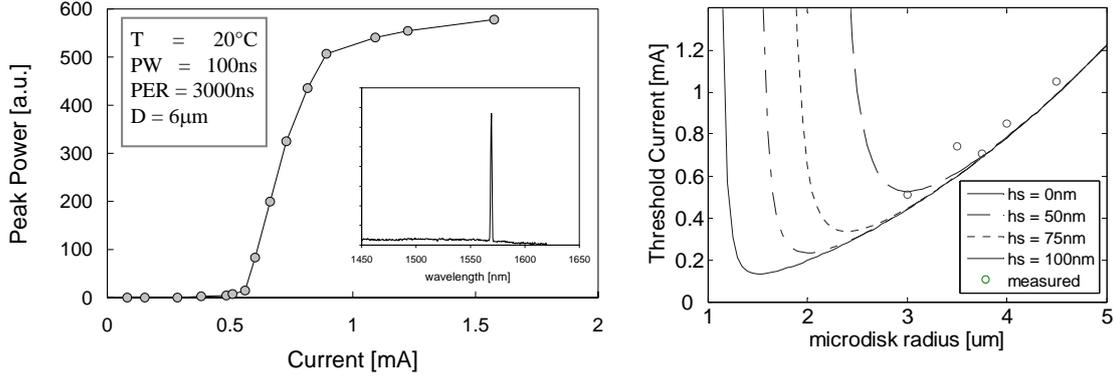


Figure 2. Left: light output vs. current for $D=6\mu\text{m}$, inset: lasing spectrum for $I=0.75\text{mA}$. Right: calculated threshold current versus disk diameter D and bottom contact slab thickness h_s . Circles denote measured values.

Table 1 Parameter values used in threshold current calculations

Parameter	Value	Parameter	Value	Parameter	Value
A	10^8 s^{-1}	G_0	1500 cm^{-1}	α_{int}	35 cm^{-1}
B	$2 \cdot 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$	n_0	$1.5 \cdot 10^{18} \text{ cm}^{-3}$	α_{scatter}	5 cm^{-1}
C	$1.6 \cdot 10^{-28} \text{ cm}^{-6} \text{ s}^{-1}$	Γ	0.068		
η_i	0.7	d_{QW}	18nm		

the p-type layer of the pn-junction. In classic substrate lasers, this is done by means of a highly doped, low-bandgap semiconductor layer. However, these layers are very absorptive and thus not useable in a thin membrane. Therefore, we implemented a tunnel junction, in combination with a second n-type contact. This tunnel junction consists of a reverse-biased Q1.2 p++/n++-junction with layer thicknesses of only 20nm and doping levels above 10^{19} cm^{-3} . This type of tunnel junction can have low absorption losses in combination with a low electrical resistivity [6]. We calculated an internal loss of 35/cm, mostly due to free carrier absorption in the tunnel junction. A second important aspect is the position of the metal contacts. They should be kept away from the optical field to avoid any excess absorption. In our design, the top contact is placed only in the centre of the microdisk, whereas the bottom contact is placed on a very thin n-type InP layer that extends laterally at the bottom of the microdisk. The bend losses of the microdisk resonator are highly dependent on this bottom contact layer thickness h_s . FDTD simulations show that for disk diameters D smaller than $6\mu\text{m}$, h_s should be smaller than 100nm. For $h_s = 50\text{nm}$, disk diameters can be even as small as $4\mu\text{m}$. The threshold current was calculated as function of these two design parameters, assuming logarithmic gain and (material) parameter values given in table 1. Results are shown in figure 2.

Fabrication and measurement Results

First, the laser heterostructure including three compressively strained InAsP quantum wells and the tunnel junction was grown by molecular beam epitaxy (MBE) on a 2 inch InP wafer. This wafer was bonded onto a Si wafer by molecular bonding (for more details, see [5]). After substrate removal, the microdisks were defined by optical lithography and were etched into the 420nm-thick bonded membrane by reactive ion

etching (RIE) using a Ti hard mask. The RIE etch was incomplete, leaving a thin bottom contact membrane of about 80nm. These structures were covered with a benzocyclobutene (BCB) film, in which contact windows were etched before depositing the top and bottom metal contact. Au-based contacts were deposited and fast-alloyed at 400°C.

Electrically injected lasing was observed for microdisks with diameters in the range 6–9µm. The P-I curve and lasing spectrum for a disk with diameter of 6µm is depicted in fig. 2 and reveals a threshold current as low as 0.55mA, and a lasing wavelength of 1570nm. For all diameters, the microdisks lase only in the radially fundamental whispering gallery modes, due to the presence of the top metal contact in the centre of the disk. For smaller top metal contacts, we also observed lasing for radially higher order modes. The current threshold as a function of diameter is also depicted in fig 2: for disk diameters smaller than 6µm, we failed to open the top contact window in the BCB-layer. However, calculated threshold current values indicate that we could reduce the threshold down to 0.25mA by reducing the diameter to 4µm. Lasing was only obtained in pulsed regime, due to the high electrical resistance of the device in combination with a poor heat sinking ability. Indeed, the voltage drop at threshold varies between 5-7V, mainly due to the non-optimal tunnel junction and non-optimal n-type metal contacts. A thermal analysis of the microdisk laser yields a thermal resistance of about 10^4 K/W for $D = 6\mu\text{m}$, what results in serious self heating. Future work includes coupling to a passive SOI-waveguide and improvement of the tunnel junction, metal contacts and etching quality.

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