YB:KYW MICROCHIP LASER

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Abstract

We present a diode pumped Yb:KYW microchip laser. Passively Q-switched and CW regimes of operation for the Yb:KYW microchip laser have been tested with a set of output couplers. A slope efficiency of 23% has been achieved for CW operation. Raman self-frequency conversion for the microchip cavity configuration have been observed.

Potassium yttrium and potassium gadolinium tungstates are known as a good hosts for efficient neodymium and ytterbium doped laser media which are used in miniature diode pumped solid-state lasers, including Raman lasers with self-frequency conversion [1-7]. Low power microchip lasers are compact, simple to fabricate, robust and operate mostly in single longitudinal mode. They found many applications in laser systems as CW and passive Q-switched coherent sources, but in most cases there is considerable interest in a passive Q-switched regime of operation of microchips due to the possibility to produce sub-nanosecond light pulses of high peak power for subsequent nonlinear frequency conversion.

Plane-parallel configuration of a microchip resonator which is on limit of cavity stability requires careful choice of gain medium for chip-set in order to get an efficient operation [8]. In our previous papers [2,9] it was experimentally shown that $Nd^{3+}:KGd(WO_4)_2$ is a laser material which is suitable for microchip applications, in spite of the fact of negative thermal lens in an active element cut along b-axis in the plane perpendicular to one of laser polarization [2]. Most of previous work on microchip lasers emitting at fundamental wavelength ~1 µm has been performed with neodymium doped materials as a gain medium, and to our knowledge there is only one paper on the experimental research of ytterbium doped laser crystal where a passive Q-switched Yb:YAG microchip performance with the plano/plano cavity configuration was described [10]. At the same time ytterbium

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doped materials are good choice for a new type of solid-state lasers - radiation balanced lasers - and can be used for optical cooling and other new applications [11].

In this work, $Yb^{3+}:KY(WO_4)_2$ crystal was experimentally investigated in plane-parallel microchip resonator under laser diode pumping. Both CW and passively Q-switched regimes of operation were realised and studied. During Q-switching experiments, stimulated Raman scattering with self-frequency conversion was achieved in the microchip configuration for the first time to our knowledge.

The main features of Yb:KYW laser medium are the broad absorption band centered at 981 nm where powerful commercial laser diodes are available, relatively large absorption coefficient (17 cm^{-1} for typical 5at% Yb^{3+} concentration that corresponds to ion concentration of $3.2 \cdot 10^{20}$ cm^{-3}), relatively inexpensive, reproducible and easy growth technology allowing to produce crystals with a high optical quality. Double tungstates are also highly efficient Raman media due to the structure symmetry related to the vibration symmetry of a molecular WO_4- group: for Yb:KYW at λ=1064 nm the picosecond Raman gain is 4.7 cm/GW, while the steady-state Raman gain amounts to 5.1 cm/GW [12]. This property considerably extends their application range in laser systems. Doped with different rare-earth element ions, double tungstates could be a good choice perspective as active media for lasers with self-frequency conversion. In our previous investigations of low power diode pumped passively Q-switched Yb:KYW lasers with bulk semi-spherical cavity we obtained tunable Raman self-frequency conversion to first Stockes with an optical efficiency up to 3.4% with regard to laser diode pump power [7]. This stimulated the continuation of our work in order to realize the microchip Raman laser.

The Yb:KYW microchip used in the experiment was made from 10at% Yb^{3+}-doped material and was cut along b-axis and polished to be 1.1 mm long. One polished surface was coated to be highly reflecting in 1020...1150 nm wavelength range and highly transmitting at the pump wavelength. The other polished surface was antireflection coated for the fundamental and for first Stokes wavelengths. The active element was mounted on the cooper heat sink to promote a symmetrical heat removal. The output coupler was 90%, 95%, 98%, and high (HR) reflectance at 1030 nm flat external mirrors. The last two mirrors provided about 2% of transmittance at 1130 nm (first Raman Stokes). The antireflection coated ~100 μm thick Cr^{4+}:YAG plate with an initial transmission of 97% was used as a passive Q-switch, which was mounted directly on the output mirror. The pump source was a multimode diode laser providing 1.2 W at 980 nm from a 100x1 μm emitting area. The light from the diode laser was delivered to the active element by the focusing system consisting of triplet collimator (NA=0.5), 4^x cylindrical telescope and a focusing lens (f=10 mm).

The output characteristics obtained for CW regime of operation are shown in Fig. 1. The best input-output curve for the microchip operation was observed for an output coupler with a reflectivity of R_{oc}=0.90. Maximum CW output power achieved in our experiments was 54 mW for ~510 mW of the incident pump power. Slope and optical efficiency were 23% and 10%, respectively. For quasi-three level systems like Yb-doped media it is difficult to estimate experimentally the part of absorbed pump power because of reabsorption and saturation effects inherent in such systems. Therefore to evaluate the laser efficiency we used the incident pump power, although the use of this parameter for the absorbed pump power leads to underestimation of the real laser efficiency.

As it is seen in Fig.1b, the spectra of microchip emission exhibit a mode structure which most likely is formed due to coupling of two Fabry-Perot etalons - a parallel sided active element and an air gap between the crystal and the output coupler which was in our experiments about 100 μm. Spectral maximum of output power, as it was expected, shifts to shorter wavelengths with increasing output coupler reflectivity.

For a passively Q-switched regime of operation the best result was obtained with the output coupler having R_{oc}=0.95 (Fig. 2a). For the maximum pump power, output average power was high as 26 mW with the optical efficiency of pumping about 5%. The lasing spectra of Q-switched regime of operation demonstrate almost the same mode structure, (see Fig. 2b) differing from CW spectra by the spacing between the mode groups The difference may be caused by influence of intracavity Cr:YAG parallel sided thin plate: it plays a role of a third Fabry-Perot etalon within a cavity. It should be noted that output emission spectrum is very sensitive to inclination of output coupler (with Cr:YAG plate attached to output mirror). In our experiments weak inclination of output mirror resulted in tuning of output laser emission within the range of 1023.5...1025 nm (see Fig.3).

In process of microchip lasing spectrum investigation we have found that spectral mode structure was changed significantly over several minutes since the switch on time of laser. The lasing spectrum evolution picture during the first several minutes after switch on is shown in Fig. 4. Most probably output emission spectrum is changed under changing the cavity parameters caused by thermal processes, which, in one's part, take place within an active crystal after switch on of pump source.

The detailed investigation of temporal characteristics for passive Q-switched regime of operation showed complicated dynamics. Depending on the cavity alignment, we observed simultaneous operation at two cavity modes with different intensities, causing high jitter and unstable output power. Most probably this behaviour is due to two reasons. The first one is the Raman self-frequency conversion process which depletes the stronger longitudinal mode and therefore promotes the build-up of the other mode. Second, since the thermal lens of the active element may be negative in one plane as in Nd:KGW [2], it can significantly influence the resonator stability.

Unfortunately, the oscilloscope used in our experiments, did not allow us to measure pulses shorter than 2 ns (half-width), although to our estimation, the half-width of pulses emitted by the microchip should have been less than 1 ns. For the maximum pump power and output mirror reflectance of 0.95, the repetition rate was about 49 kHz. Assuming the pulse half-width to be 2 ns, the peak power obtained from the microchip was on the order of 265 W.

The first Stokes of Raman generation was observed for HR and R=0.98 output couplers (see Fig. 2b). Frequency conversion was estimated to take place for the strongest spectral group of fundamental emission. However, if in the fundamental spectrum two groups of spectral modes with approximately equal intensities are observed, Raman spectrum exhibits two lines as well. The best result for Raman self-frequency conversion in our microchip was achieved for a 0.95 output coupler, where at maximum pump power we obtained 2 mW of average Stokes power.

In conclusion, we present for the first time to our knowledge the diode-pumped Yb:KYW microchip laser operating both in CW and in passive Q-switched regimes. Also we demonstrated here the first diode-pumped Raman microchip laser with self-frequency conversion.

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Figure captions

Fig.1. Output characteristics of CW Yb:KYW microchip laser:
a) input-output power curve;
b) spectra of emission.

Fig.2. Output characteristics of a passively Q-switched Yb:KYW microchip laser:
a) input-output power curve;
b) spectra of emission.

Fig.3. Output spectrum tuning of Q-switched Yb:KYW microchip laser.

Fig.4. Temporal behaviour of Q-switched Yb:KYW microchip laser output emission spectrum; t - time interval, passed from the switch on time of laser.

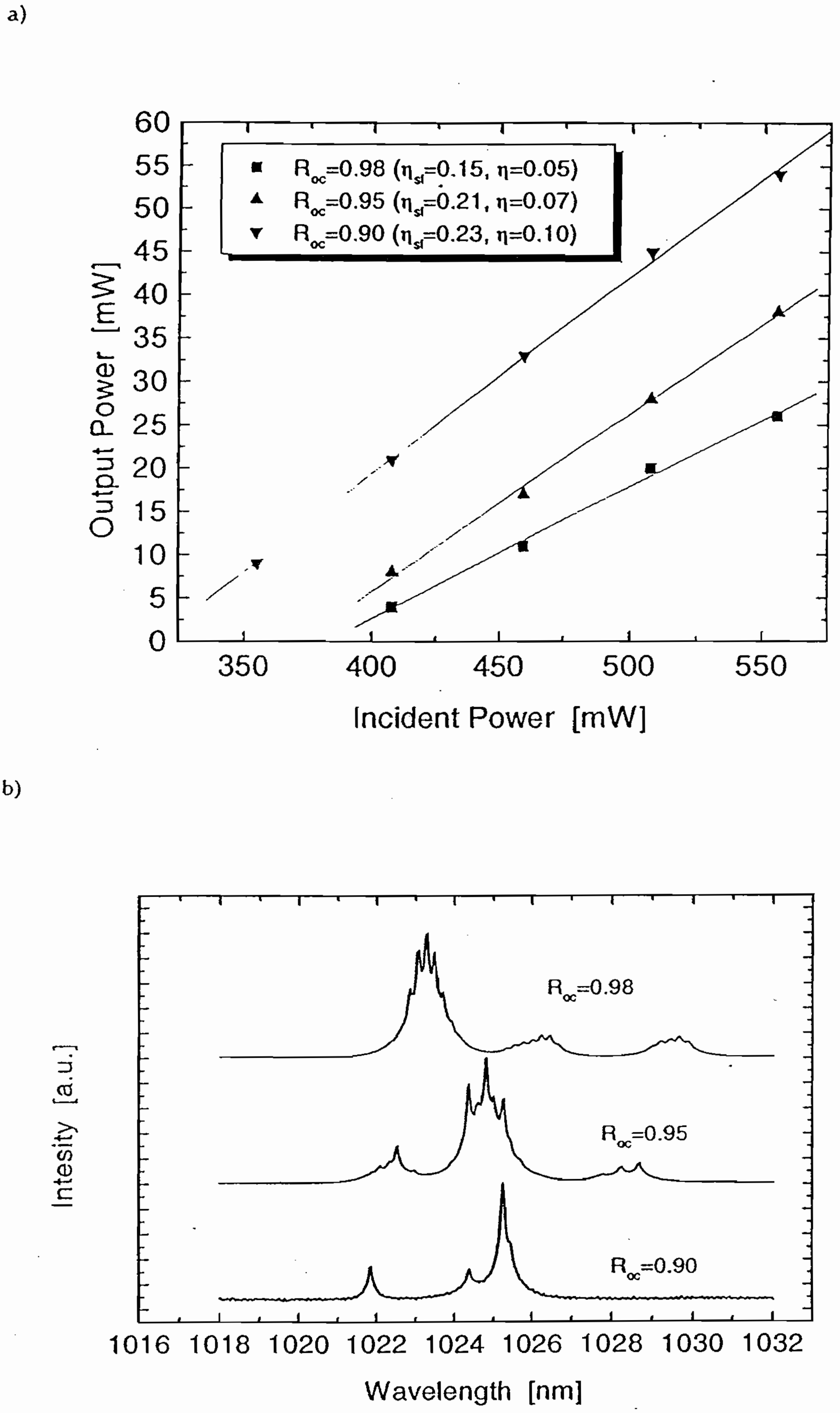
a)
60
55
50
45
40
35
30
25
20
15
10
5
0
Output Power [mW]
R_oc=0.98 (η_sl=0.15, η=0.05)
R_oc=0.95 (η_sl=0.21, η=0.07)
R_oc=0.90 (η_sl=0.23, η=0.10)
350
400
450
500
550
Incident Power [mW]
b)
R_oc=0.98
R_oc=0.95
R_oc=0.90
Intesity [a.u.]
1016
1018
1020
1022
1024
1026
1028
1030
1032
Wavelength [nm]

Fig. 1.

a)

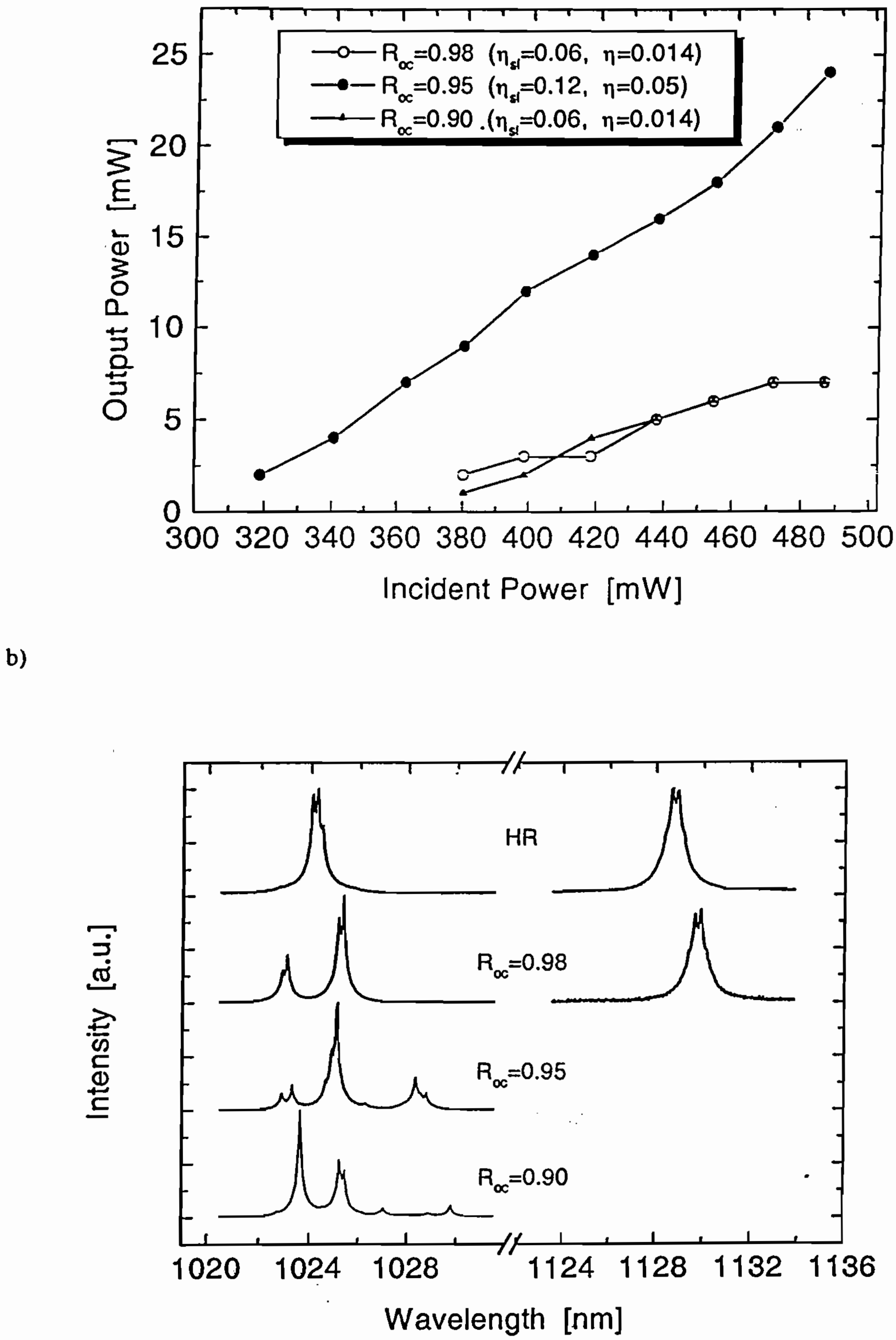
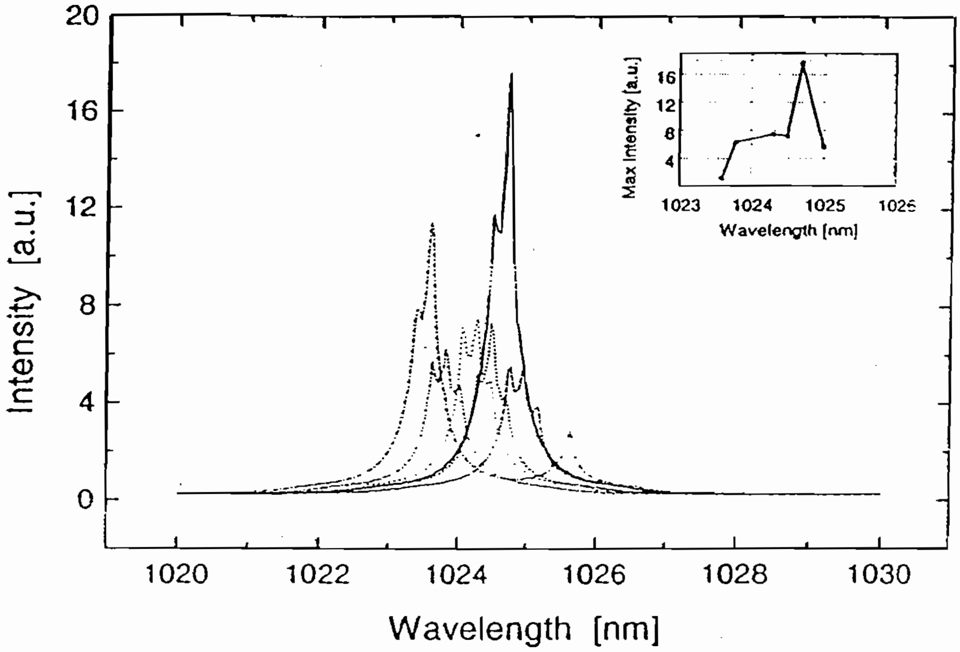
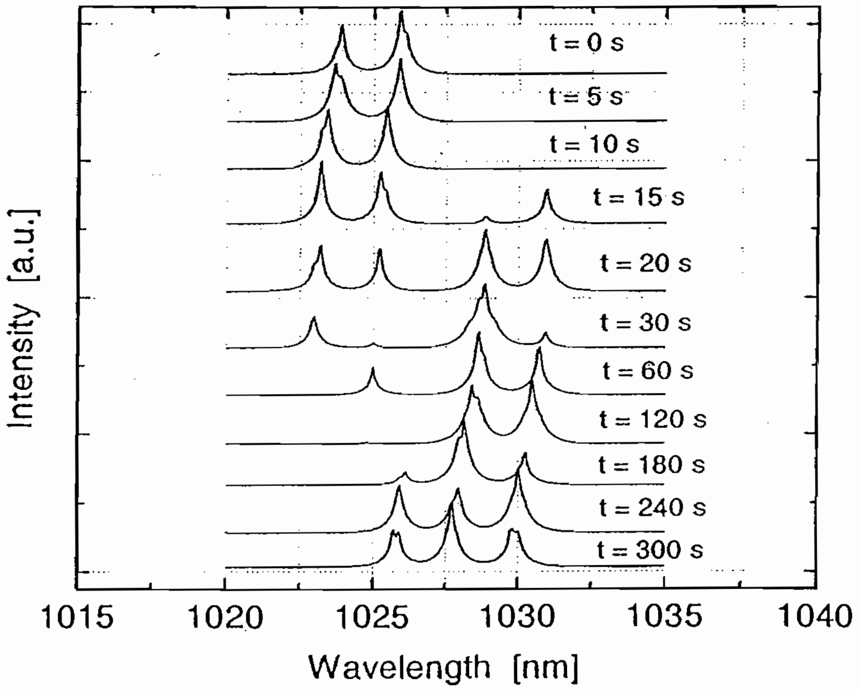

R_oc=0.98 (η_sl=0.06, η=0.014)
R_oc=0.95 (η_sl=0.12, η=0.05)
R_oc=0.90 .(η_sl=0.06, η=0.014)
Output Power [mW]
0
5
10
15
20
25
300
320
340
360
380
400
420
440
460
480
500
Incident Power [mW]
b)
HR
R_oc=0.98
R_oc=0.95
R_oc=0.90
Intensity [a.u.]
1020
1024
1028
1124
1128
1132
1136
Wavelength [nm]

Fig. 2.



Intensity [a.u.]
20
16
12
8
4
0
1020
1022
1024
1026
1028
1030
Wavelength [nm]
Max Intensity [a.u.]
16
12
8
4
1023
1024
1025
1026
Wavelength [nm]

Fig. 3.



t = 0 s
t = 5 s
t = 10 s
t = 15 s
t = 20 s
t = 30 s
t = 60 s
t = 120 s
t = 180 s
t = 240 s
t = 300 s
Intensity [a.u.]
1015
1020
1025
1030
1035
1040
Wavelength [nm]

Fig. 4.