RAPORT STIINTIFIC SINTETIC

Etapa I. Octombrie - Decembrie 2011

I.1 Au fost efectuate studii privind obtinere ('scrierea') de ghiduri de unda in medii laser dopate cu ionul de Nd, iar pe baza acestor studii au fost stabilite caracteristici ale mediilor Nd:YAG, Nd:YVO_4 si Nd:$GdVO_4$ care vor fi utilizate in experimente.

Experimental, a fost testata capabilitatea sistemului de scriere cu laserul fs (prezentat in Fig. 1) a unei structuri tip ghid de unda in volumul unei sticle de dimensiune $18\times18\times0.5$ mm^3. Pentru focalizare s-a utilizat un obiectiv de microscop 100x cu apertura numerica NA = 0.5 si distanta de lucru de 12 mm. S-a realizat un set de 3 grupe de linii cu lungimea de 1 mm, viteza de scriere de 1mm/s si distanta intre grupe de 0.5 mm. Fiecare grupa de linii cuprinde cate 5 linii, la o distanta intre ele de 100 µm. O imagine de miscroscopie optica a structurii create este aratat in Fig. 2a. Prima structura din stanga a fost realizata folosind o energie laser de 20 nJ (0.28 J/cm^2), urmatoarea grupa de linii cu energia de 12.5 nJ (0.17 J/cm^2), iar ultima cu energia de 5nJ (0.07 J/cm^2). In urma masuratorilor de profilometrie a rezultat ca la energia de 20 nJ si la o focalizare a fascicolului laser pe suprafata probei, s-a produs ablatia materialului obtinandu-se canale. Astfel, folosind pulsuri laser cu energia de pana la 20 nJ, se poate induce o modificare a indicelui de refractie necesara obtinerii structurii ghid de unda. Pentru realizarea acestor structuri s-au trasat in volumul sticlei prin absorbtia neliniara a radiatiei laser, linii de lungime 17 mm, cu o distanta intre linii de 0.5 mm si o viteza de scriere de 1 mm/s (Fig. 2b).

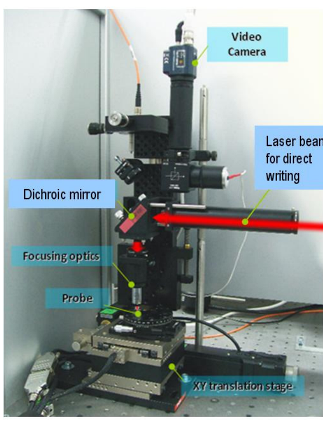


Fig. 1 Statie de lucru pentru scriere directa cu laserul.

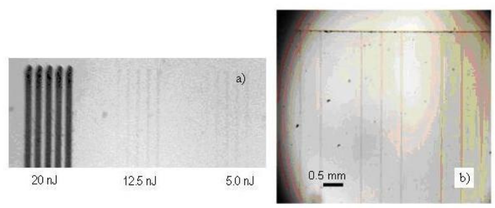


Fig. 2 a) Imagine de microscop a unei probei de sticla iradiate cu laserul fs la diferite energii ale pulsului laser. **b)** Structuri realizate in volumul sticlei.

Etapa II. Ianuarie - Decembrie 2012

II.1. Au fost realizate ghiduri de unda (de diferite geometrii) in mediul Nd:YAG de tip cristal si a fost obtinuta emisie laser la 946 nm, 1.06 si 1.32 µm folosind pompajul cu dioda laser la 807 nm.

Mentionam ca aceste rezultate au fost primele pe plan mondial pentru astfel de sisteme laser.

Montajul experimental utilizat pentru scrierea ghidurilor de unda este prezentat in Fig. 3. Laserul de tip Ti:safir emite pulsuri cu durata de 200 fs, repetitie de 2 kHz si energie maxima de 1 mJ, la lungimea de unda de 775 nm; fasciculul laser a fost caracterizat de factorul M^2= 1.5. Fasciculul a fost focalizat in cristalul laser in care se realizeaza ghidurile de unda cu ajutorul unui obiectiv optic, iar energia pulsurilor laser a fost modificata folosind un sistem optic format dintr-o lama de unda ($\lambda/2$), un polarizer (P) si un filtru neutru (P). Mediul activ a fost pozitionat pe un sistem Oxyz motorizat, cu miscare controlabila pe toate cele trei directii. Trei obiective optice, cu marirea 100x (NA= 0.5), 40x (NA= 0.65) si 20x (NA= 0.40) au fost utilizate.

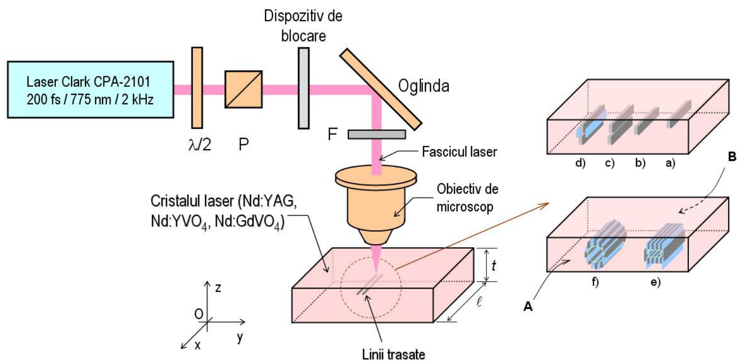


Fig. 3 Montajul experimental folosit pentru scrierea ghidurilor de unda in mediile laser Nd:YAG, $Nd:YVO_4$ si $Nd:GdVO_4$.
P: polarizor; λ/2= lama 'jumatate de unda'; F: filtru neutru.

Pentru inceput, au fost realizate modificari ale indicelui de refractie in doua cristale Nd:YAG, primul cu 0.7-at.% Nd (grosime de 3 mm si lungime de 8 mm) iar al doilea cu 1.1-at.% (3 mm grosime, 5 mm lungime). Dupa scriere, mediile au fost slefuite pe suprafetele exterioare (A si B in Fig. 3) si investigate cu ajutorul unui microscop. Figura 4a prezinta trasele realizate cu obiectivul 100x in mediul 0.7-at.% Nd:YAG. Calculele au aratat ca fluenta minima a fasciculului laser pentru care scrierea a fost posibila a fost de 3.4 (±0.3) J/cm^2. In cazul obiectivului 20x au fost realizare trase in mediul laser pana o adancime de 300 μm (Fig. 4b) distanta intre linii fiind aleasa de 50 μm (Fig. 4b) sau de 75 μm (Fig. 4c). Schimbarile de indice de refractie sunt evidente in poza interioara a Fig. 4c, mediul Nd:YAG fiind plasat intre doi polarizori incrucisati. Fluenta fasciculului laser a fost de 7.8 la 10.7 J/cm^2.

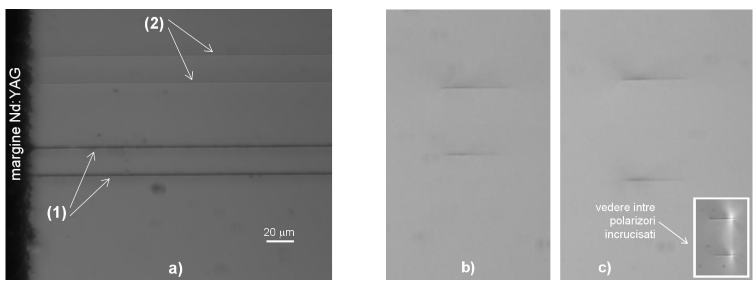


Fig. 4 a) Inscriptionari realizate cu obiectivul 100x la suprafata mediului Nd:YAG **(1)** si la o distanta de 2 μm sub suprafata mediului **(2)**. Trase realizate cu obiectivul 20x la adancimi de **b)** 250 si **c)** 300 μm.

Structuri mai complexe au fost realizate folosind obiectivul cu marirea 20x. Astfel, au fost obtinute trase simple (paralele) situate la distanta de 40 μm (Fig. 5a, b), ghiduri alungite ca in Fig. 5c (schimbarea de indice de refractie s-a facut prin trasarea a cate doua perechi de linii suprapuse si a unei perechi de linii deplasate la 4 μm, precum si de structuri complexe de tip dreptunghi (Fig. 5d), de tip cilindru cu sectiune circulara (Fig 5e) sau eliptica (Fig. 5f). Aceste structuri au fost scrise la o adancime de ~300 μm in Nd:YAG.

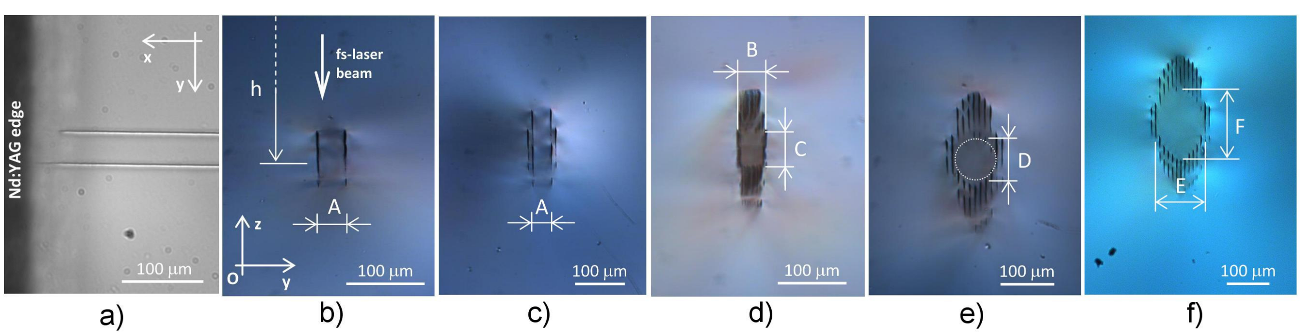


Fig. 5 Inscriptionari realizate in mediul Nd:YAG: **a)** linii paralele la suprafata mediului, distantate la 40 μm; **b)** structura ghid de unda de tip 'doi pereti', distanta A= 40 μm (**WG-1**); **c)** ghid de unda cu structura alungita pe axa Oy (**WG-2**); **d)** structura de tip dreptunghi (B= 40 μm, C= 50 μm), **DWG-3**; **e)** structura circulara (D= 80 μm), **DWG-4** si **e)** structura eliptica (E= 120 μm, F= 165 μm), **DWG-5**.

Pentru a masura pierderile acestor structuri a fost construit montajul prezentat in Fig. 6. Fasciculul (polarizat) al unui laser HeNe (632.8 nm) a fost focalizat (cu lentila L) in structurile de tip ghid de unda, iar puterea radiatiei laser a fost masurata inainte si dupa fiecare ghid. Pierderile au fost de 0.4 dB/cm pentru propagarea in Nd:YAG, 1.1 dB/cm pentru WG-1, 1.4 dB/cm pentru WG-2, 2.2 dB/cm pentru DWG-3, 1.6 dB/cm pentru DWG-4 si 1.0 dB/cm pentru DWG-5.

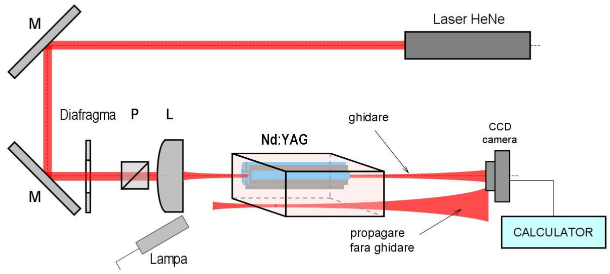


Fig. 6 Montaj experimental utilizat pentru caracterizarea ghidurilor de unda. M: oglinda; P: polarizor; L: lentila

Proprietatile de emisie laser au fost investigate intr-un montaj experimental similar cu cel prezentat in Fig. 7. Pompajul s-a facut cu o dioda laser cu emisie la λ_p= 807 nm (fibra optica cu diametrul de 600 μm, NA= 0.22). Rezonatorul optic a fost unul plan-plan, cu oglinzile HRM si OCM plasate cat mai aproape de suprafetele mediului Nd:YAG.

Caracteristici ale emisiei laser la 1.06 μm, in regim de pompaj quasi-cw, sunt prezentate in Fig. 8. Spre exemplu, ghidul de unda DWG-5 a emis pulsuri laser cu energia de 1.4 mJ (pentru pulsuri de pompaj cu energia de 9.0 mJ), panta eficientei laser laser fiind η_s= 0.22. Ghidul de unda de tip 'doi pereti' WG-1 a livrat pulsuri laser cu energia de 0.92 mJ si panta a eficientei η_s= 0.28. A fost facuta o investigatie sistematica a performantelor emisiei laser la 1.06 si 1.32 μm, in regim de pompaj quasi-cw si cw, iar datele obtinute sunt prezentate sistematic in Tabelul I.

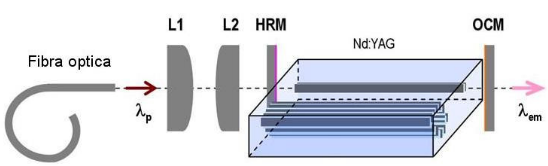


Fig. 7 Montaj experimental utilizat pentru caracterizarea ghidurilor de unda. M: oglinda; P: polarizor; L: lentila.

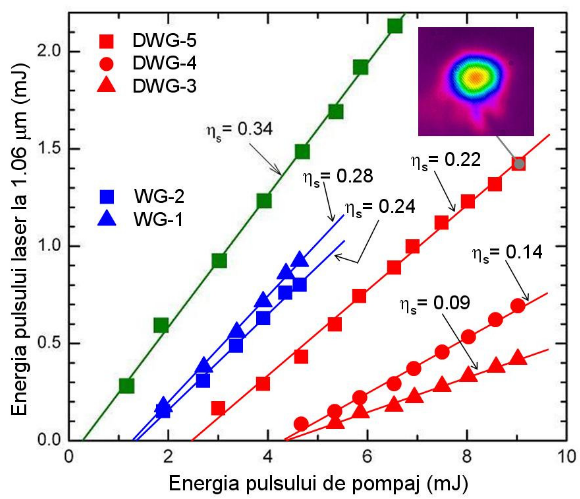


Fig. 8 Energia pulsului laser la 1.06 μm in functie de energia pulsului de pompaj la 808 nm pentru diferite ghiduri de unda. Este prezentata si o distributie (2D) a fascicolului laser obtinut de la ghidul de unda DWG-5.

Mentionam ca au fost facute incercari de a obtine emisie laser la 946 nm (pe tranzitia de tip quasi-4 nivele, $^4F_{3/2} \rightarrow {}^4I_{9/2}$), aceasta fiind realizata pentru ghidurile de unda DWG-5 si WG-1. Energia pulsului de pompaj la prag a fost de 7.5 si 3.2 mJ, respectiv, energia pulsului laser fiind 0.12 si 0.36 mJ, respectiv.

Tabelul I. Energia maxima a pulsului laser si nivelul maxim al puterii laser la 1.06 si 1.32 μm obtinute in experimente.

λ_{em} (μm)	Mod de operare	Configuratia	Nivel de pompaj (mJ pulsat/W cw)	Laser (mJ / W)	Panta eficientei, η_s
1.06	quasi-cw	bulk	9.0	2.96	0.34
		DWG-5	9.0	1.40	0.22
		DWG-3	9.0	0.40	0.09
		WG-1	4.6	0.92	0.28
	cw	bulk	3.8	1.30	0.39
		DWG-5	3.8	0.54	0.17
		WG-1	3.2	0.49	0.20
1.3	quasi-cw	bulk	9.1	2.10	0.25
		DWG-5	9.1	0.40	0.10
		DWG-3	9.1	0.17	0.05
		WG-1	4.6	0.40	0.17
	cw	bulk	3.2	0.55	0.20
		WG-1	3.2	0.11	0.05

II.2 Au fost facute cercetari pentru generarea de pulsuri laser in regim comutat, utilizand mediul laser Nd:YAG si cristale cu absorbtie saturabila de tip Cr^{4+}:YAG, precum si pentru proiectarea unui laser miniatural de acest tip. Aceste rezultate vor fi utile in Etapa a IV-a acestui contract.

II.3 S-au facut studii privind obtinerea de medii ceramice Nd:YAG prin metoda sintezei in stare solida.

Pulberi de oxid de ytriu, oxid de neodymium (99.99%, 20-40 nm) si oxid de aluminiu (99.99%; faza gamma, 20-50 nm) ce au fost uscate in prealabil in etuva la 250^0C timp de 24 de ore pentru eliminarea apei, au fost cantarite in raport stoiechiometric pentru obtinerea a 30 g granat de ytriu si aluminiu dopat 1% cu Nd. Dupa cantarire, pulberile au fost amestecate impreuna cu adaos de tetra ortosilicat, 0.5% din masa pulberilor cantarite, ca ajutor sinterizare, pe o moara intr-un recipient din oxid de aluminiu in alcool etilic absolut cu ajutorul unor bile din oxid de aluminium. Amestecarea s-a realizat prin rostogolirea recipientului cu o turatie de 60 rot/min timp de 72 de ore. Cu 4 ore inainte de finalizarea amestecarii a fost adaugat PEG 400 (polietilen glycol) pentru a evita aglomerarea particulelor.

Dupa procesul de amestecare a urmat uscarea pulberilor. Acest lucru s-a realizat cu ajutorul instalatiei de uscare prin spreiere tip Buchi 250 in bucla inerta cu sistem de racire tip B-295. Parametrii de functionare au fost: aspiratie 100%, pompa 50%, temperatura de intrare 88^0C, temperature de iesire 36^0C, air flow 4cm. Procesul a constat in pulverizarea amestecului la o temperatura superioara cu 10^0C decat temperatura de fierbere a solventului, iar la trecerea acestuia printr-un ciclon, pulberile uscate sunt colectate in partea inferioara a acestuia. Pulberile astfel obtinute au fost puse din nou la etuva la 250^0C timp de 24 de ore pentru indepartarea urmelor de alcool etilic absolut si apa absorbita din atmosfera.

A urmat procesul de compactizare. La o temperatura de 100^0C pulberile au fost presate uniaxial cu presa de la MTI (model EQ-YLJ-100T), intr-o matrita din inox sub forma de pastile, la o presiune de 100 bari. Dimensiunile celor trei pastile obtinute au fost: diametrul 1.27 mm si inaltime de 3mm. Pastilele au fost puse intr-un creuzet din oxid de alumina si puse la copt la o temperature de 700^0C pentru indepartarea reziduurilor organice. Dupa ce s-au racit, pastilele au fost puse in folie de plastic si sigilate. In continuare, au fost puse intr-un recipient si presate izostatic cu ajutorul unei prese model ISOLAB FPG 7680 (Stansted Fluid Power Ltd., UK). Parametrii de presare au fost: presiunea 2450 bari timp de 30 de minute. Sinterizarea a fost realizata in cuptorul tip LHT 02/18 (Nabertherm, Germania). Pastilele au fost puse in creuzet din oxid de aluminiu si inconjurate de pulberea ramasa si acoperite cu un capac din acelasi material ca si creuzetul. Temperatura de sinterizare a fost de 1730^0C, timp de 16 ore. Rata de crestere a temperaturii a fost de 62^0C/ora, iar rata de racire a temperaturii a fost de 40^0C/ora. In urma sinterizarii, probele si-au micsorat dimensiunile cu aproximativ 29%, fapt ce se explica prin compactizarea microgranulelor de YAG si eliminarea porilor dintre acestea.

O proba a fost slefuita la calitate laser pe ambele fete cu ajutorul instalatiei de polizare si slefuire tip Logitech pentru analize spectroscopice (Fig. 9a), iar o alta a fost sparta pentru a se putea analiza structura sa cu ajutorul SEM. Granulele monocristaline continute au diametrul de 5-20 μm (Fig. 9b, c), iar calitatea optica este determinata de dimensiunile granitelor granulei si de numarul si dimensiunile porilor.

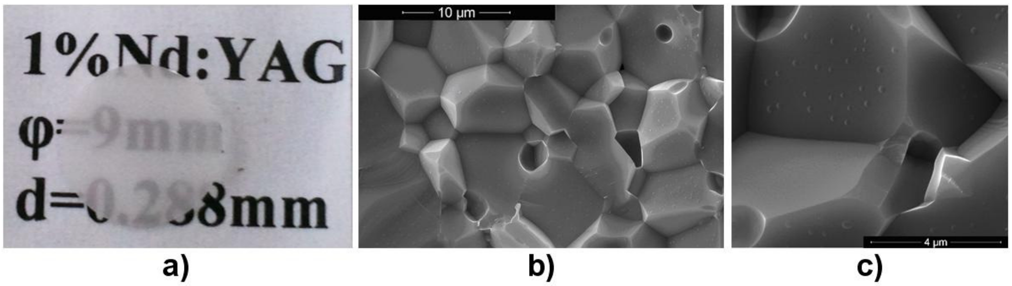


Fig. 9 a) Fotografie a unui mediu Nd:YAG ceramic obtinut prin tehnici ceramice. Imagini SEM ale granulelor monocristaline la scara de: **b)** 10 μm si **c)** 4 μm.

Etapa III. Ianuarie - Septembrie 2013

III.1. Ghiduri de unda in mediul Nd:YAG de tip ceramic

In experimente am utilizat medii ceramice cu diferite concentratii si dimensiuni: 0.7-at.% Nd, 5 mm (R12077-1); 0.7-at.% Nd:YAG, 8 mm (R12077-4); 1.1-at.% Nd:YAG, 5 mm (R12078-2) si 1.1-at.% Nd:YAG, 8 mm (R12078-4). Pentru scrierea ghidurilor de unda am folosit acelasi montaj din Fig. 3, energia pulsului laser necesar pentru incriptionare fiind determinata pentru fiecare mediu ceramic.

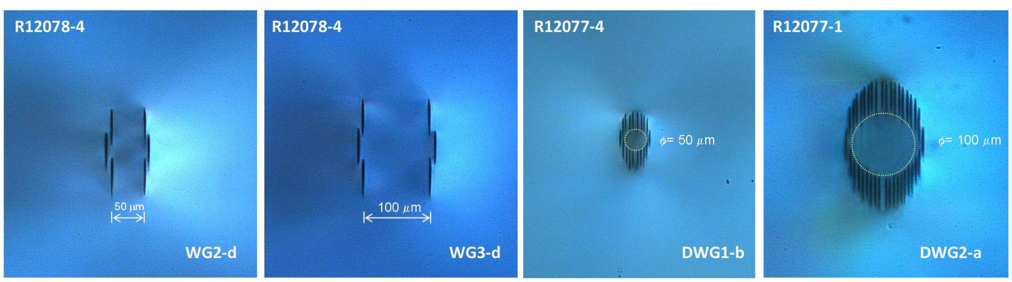


Fig. 9 Exemple de ghiduri de unda realizate in diferite medii Nd:YAG ceramice: Ghiduri de tip 'doi pereti', cu distanta de 50 μm (WG2-d) si 100 μm (WG3-d) si de tip circular, cu diametrul de 50 μm (DWG1-b) sau de 100 μm (DWG2-a).

In fiecare mediu Nd:YAG ceramic au fost realizate ghiduri de unda de tip 'doi pereti', cu distantele intre linii de 50 si 100 μm, precum si ghiduri de unda ‚ingropate' de tip circular, cu diametrele de 50 si 100 μm. Cateva dintre aceste structuri sunt aratate in Fig. 9. Pierderile la propagarea unui fascicul laser HeNe (632.8 nm) au fost masurate ca fiind intre 0.50 si 1.35 dB/cm pentru ghidurile de tip 'doi pereti' si in intervalul 1.14 la 2.96 dB/cm pentru ghidurile 'ingropate' de tip circular; pierderile pentru propagarea in Nd:YAG au fost de 0.21 la 0.45 dB/cm.

A fost obtinuta emisie laser la 1.06 μm si au fost masurate performatele emisiei in toate ghidurile de unda. Spre exemplu, Fig. 10 prezinta energia pulsurilor laser emise de ghidurile de unda 'ingropate' cu diametrul de 100 μm. in regim de pompaj quasi-cw (rata de repetitie de 2 Hz, durata a pulsului de pompaj de 1 ms). Astfel, ghidul de unda DWG4-d (realizat in mediul R12078-4) a emis pulsuri laser cu energia de 2.74 mJ, pulsurile de pompaj avand energia de 13.1 mJ, panta emisie laser a fost η_s= 0.25.

Eficienta de absorbtie a radiatiei de pompaj, in mediul liber Nd:YAG, a fost de η_a= 0.78. Pe de alta parte, ghidul de unda DWG2-a (realizat in mediul R12077-1) a furnizat pulsuri laser cu energia de 1.5 mJ pentru pompaj cu pulsuri cu energia de 12.5 mJ, cu panta a emisiei η_s= 0.16; in acest caz eficienta de absorbtie in Nd:YAG (mediul liber) a fost η_a= 0.61.

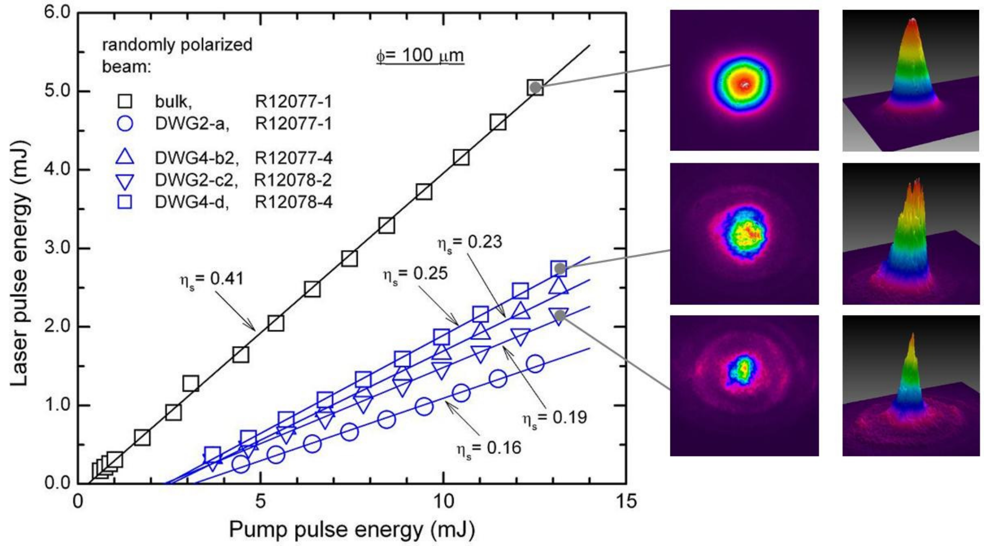


Fig. 10 Energia pulsului laser la 1.06 μm in functie de energia pulsului de pompaj la 807 nm pentru ghidurile de unda 'ingropate' cu diametrul de 100 mm realizate in mediile laser Nd:YAG ceramice. Sunt prezentate (in dreapta) si distributiile 2D si 3D, in camp apropiat, ale fasciculelor laser.

In Fig. 11 sunt prezentate performantele emisie laser la 1.06 μm in regim de operare cw a ghidurilor de unda de tip 'doi pereti', cu distanta intre linii de 50 μm. Astfel, ghidul de unda WG2-d (realizat in mediul Nd:YAG ceramic R12078-4) a emis 0.42 W pentru pompaj cu putere la 807 nm de 2.22 W, panta a emisiei (η_s) de 0.265. Pe de alta parte, ghidul WG2-a (obtinut in Nd:YAG cu indicativul R12077-1) a emis 0.22 W putere cw pentru pompaj cu 2.26 W, panta η_s fiind 0.175. Eficienta de absorbtie a radiatiei de pompaj in mediul liber a fost η_a= 0.90 pentru mediul R12078-4 si putin mai scazuta, η_a= 0.73, pentru mediul R12078.

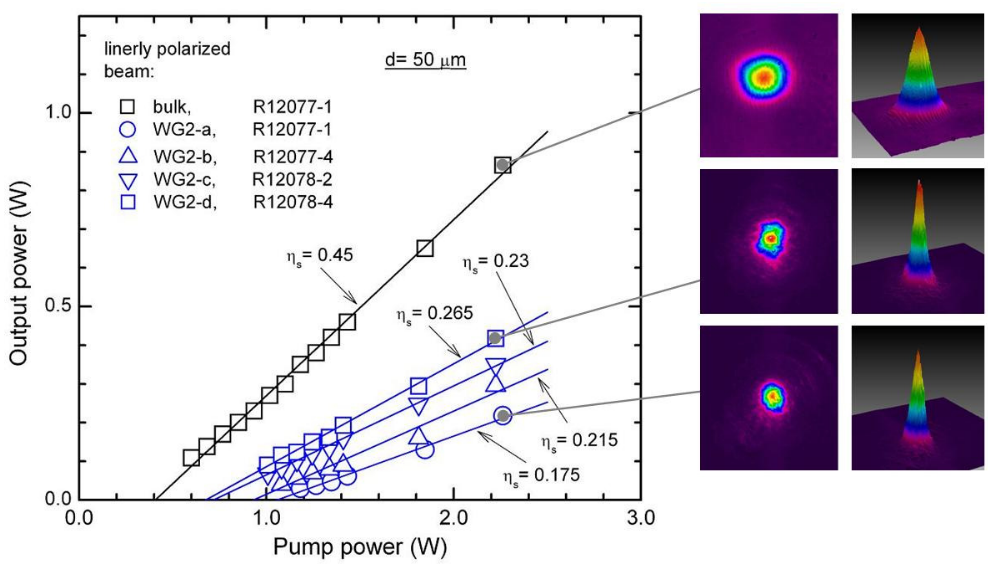


Fig. 11 Puterea fasciculului laser la 1.06 μm in functie de puterea de pompaj incidenta pe mediile Nd:YAG ceramics, pentru ghidurile de unda de tip 'doi pereti' cu distanta intre linii de 50 μm. Sunt ilustrate si distributiile 2D si 3D, in camp apropiat, ale fasciculelor laser.

Rezultatele obtinute in toate mediile Nd:YAG ceramice, pentru emisie in regim cw si quasi-cw sunt prezentate sistematic in Tabelul II. Mentionam ca acestea sunt, ca si in cazul mediilor Nd:YAG de tip cristal, primele date privind emisia folosind pompajul cu diode laser a unor ghiduri de unda obtinute prin metoda scrierii directe cu laser cu emisie in domeniul femtosecundelor.

Tabelul II. Energia maxima a pulsului laser si nivelul maxim al puterii laser la 1.06 μm obtinute de la mediile Nd:YAG ceramice. Albastru: fascicul 'linearly polarized'; Negru: fascicul 'randomly polarized'.

Mediul laser	Mod de operare	Configuratia	Nivel de pompaj (mJ pulsat/W cw)	Laser (mJ / W)	Panta eficientei, η_s
R12077-1 (0.5-at.% Nd:YAG, 5 mm)	quasi-cw	bulk	12.5	5.1	0.41
		DWG1-a (ϕ= 50 μm)	12.5	2.7	0.24
		DWG2-a (ϕ= 100 μm)	12.5	1.5	0.16
		WG2-a (d= 50 μm)	4.7	0.59	0.16
		WG3-a (d= 100 μm)	4.7	0.57	0.15
	cw	bulk	3.6	1.4	0.40
		DWG1-a (ϕ= 50 μm)	3.6	0.64	0.26
		DWG2-a (ϕ= 100 μm)	-	-	-
		WG2-a (d= 50 μm)	1.8	0.22	0.18
		WG3-a (d= 100 μm)	2.3	0.24	0.17
R12077-4 (0.5-at.% Nd:YAG, 8 mm)	quasi-cw	bulk	13.2	5.95	0.46
		DWG1-b (ϕ= 50 μm)	13.2	2.6	0.24
		DWG3-b2 (ϕ= 50 μm)	13.2	3.9	0.36
		DWG4-b2 (ϕ= 100 μm)	13.2	2.5	0.23
		WG2-b (d= 50 μm)	4.9	0.8	0.22
		WG3-b (d= 100 μm)	4.9	0.55	0.16
	cw	bulk	3.7	1.54	0.45
		DWG1-b (ϕ= 50 μm)	3.7	0.57	0.29
		DWG3-b2 (ϕ= 50 μm)	3.7	0.9	0.32
		DWG4-b2 (ϕ= 100 μm)	3.7	0.49	0.24
		WG2-b (d= 50 μm)	2.2	0.3	0.21
		WG3-b (d= 100 μm)	2.2	0.17	0.16
R12078-2 (1.1-at.% Nd:YAG, 5 mm)	quasi-cw	bulk	13.2	5.5	0.43
		DWG2-c1 (elipsa)	13.2	2.5	0.23
		DWG2-c2 (ϕ= 100 μm)	13.2	2.2	0.19
		WG2-c (d= 50 μm)	4.9	1.0	0.19
	cw	bulk	3.7	1.4	0.41
		DWG2-c1 (elipsa)	3.7	0.37	0.19
		DWG2-c2 (ϕ= 100 μm)	3.7	0.27	0.13
		WG2-c (d= 50 μm)	2.2	0.35	0.23
R12078-4 (1.1-at.% Nd:YAG, 8 mm	quasi-cW	bulk	13.2	5.5	0.43
		DWG2-d (ϕ= 100 μm)	13.2	2.2	0.2
		DWG4-d (ϕ= 100 μm)	13.2	2.7	0.25
		WG2-d (d= 50 μm)	4.9	1.1	0.27
		WG3-d (d= 100 μm)	4.9	0.7	0.18
	cw	bulk	3.7	1.3	0.38
		DWG2-d (ϕ= 100 μm)	3.5	0.26	0.21
		DWG4-d (ϕ= 100 μm)	3.7	0.4	0.22
		WG2-d (d= 50 μm)	2.2	0.4	0.26
		WG3-d (d= 100 μm)	2.2	0.25	0.18

III.2 Ghiduri de unda in mediul Nd:YVO_4

Au fost realizate incriptionari cu laserul cu emisie in femtosecunde in mediul uniaxial Nd:YVO_4. Spre exemplu, in Fig. 12 sunt prezentate diferite ghiduri de unda, de tip 'doi pereti' (Fig. 12a) sau de tip (circular (Fig. 12b, c) obtinute intr-un mediu 0.5-at.% Nd:YVO_4 (c-cut) cu grosimea de 5 mm. Se afla in desfasurare experimente de emisie laser folosind pompajul optic cu diode laser.

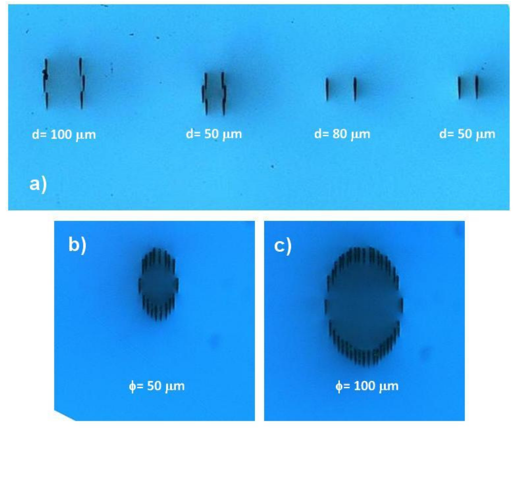


Fig. 12 Ghiduri de unda de tip **a)** 'doi pereti' si de tip circular cu diametrul de **b)** 50 μm si **c)** 100 μm realizate in Nd:YVO_4.

REZULTATE PUBLICATE

ARTICOLE ISI

Nr. crt.	Autori, titlu articol	Revista (volum, numar, pagini, an)	Factor de impact pe anul 2012
1.	N. Pavel, G. Salamu, F. Voicu, F. Jipa, M. Zamfirescu, and T. Dascalu, "Efficient laser emission in diode-pumped Nd:YAG buried waveguides realized by direct femtosecond-laser writing"	Laser Physics Letters **10** (9), 095802 (2013)	7.714
2.	G. Salamu, F. Voicu, N. Pavel, T. Dascalu, F. Jipa, and M. Zamfirescu, "Laser emission in diode-pumped Nd:YAG single-crystal waveguides realized by direct femtosecond-laser writing technique"	Rom. Reports in Physics **65** (3), 943-953 (2013).	1.12
3.	T. Dascalu, G. Salamu, O. Sandu, F. Voicu, and N. Pavel, "Novel laterally pumped by prism laser configuration for compact solid-state lasers"	Laser Physics Letters **10** (5), 055804 (2013)	7.714

- Rezultate recente au fost trimise spre prezentare la o conferinta internationala:

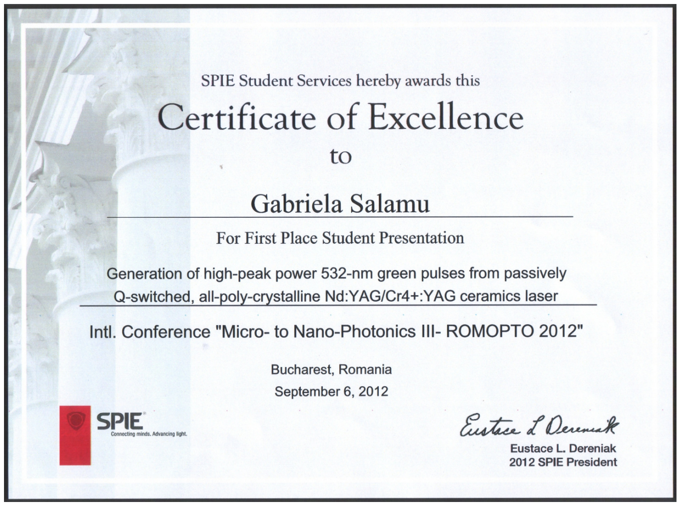
  G. Salamu, F. Jipa, M. Zamfirescu, and N. Pavel, "Laser Emission from Nd:YAG Laser Waveguides Realized by Femtosecond-Laser Writing Techniques," 2014 Photonics Europe SPIE Conference, 14-17 April 2014, Brussels, Belgium

  si se afla in pregatire 2 (doua) manuscrise care vor fi trimise pentru posibila publicare in reviste ISI.

PREZENTARI LA CONFERINTE

Nr. crt.	Autori, titlu articol	Denumire Conferinta	Tip de prezentare
1.	N. Pavel and T. Dascalu, "High-peak power passively Q-switched Nd:YAG/Cr^{4+}:YAG lasers"	International Student Conference on Photonics 2012, SPIE Student Chapter, 8-11 May 2012, Sinaia, Romania. Book of abstracts, ISSN 2284-9750, p. 79	Prezentare invitata (http://iscp.inflpr.ro/data/uploads/program/bookabsiscp12_final.pdf)
2.	N. Pavel, G. Salamu, O. Sandu, A. Ionescu, C. Brandus, F. Voicu, and T. Dascalu, "Efficient, simultaneous dual-wavelength emission at 1.06 and 1.34 µm in Nd:$GdVO_4$ laser crystal"	5th EPS-QEOD EUROPHOTON CONFERENCE, Solid State, Fibre, and Waveguide Coherent Light Sources, 26-31 August, 2012, Stockholm, Sweden, presentation TuP.11; Europhysics Conference Abstract Vol. 36 E; ISBN 2-914771-778-9	Prezentare poster http://2012.europhoton.org/files/ep2012print.pdf
3.	G. Salamu, A. Ionescu, C. Brandus, O. Sandu, N. Pavel, T. Dascalu, "Generation of high-peak power 532-nm green pulses from passively Q-switched, all-poly-crystalline Nd:YAG/Cr^{4+}:YAG ceramics laser"	Micro- to Nano-Photonics III, ROMOPTO 2012, 10th International Conference on Optics, 3-6 September, Bucharest, Romania, presentation I.P.5.	Prezentare poster http://romopto.inflpr.ro/ProgramFinal.pdf

NOTA: Aceasta prezentare a primit diploma ”**Certificate of Excellence for First Place Student Presentation**”. Lucrarea este publicata in volumul SPIE dedicat acestei conferinte, Proc. SPIE **8882**, ROMOPTO 2012: Tenth Conference on Optics: Micro- to Nanophotonics III, 888206 (June 10, 2013), cu mentiunea ”**Best Poster SPIE Award**”.



4.	G. Salamu, F. Voicu, F. Jipa, M. Zamfirescu, N. Pavel, “Direct femtosecond laser written waveguides in Nd:YAG”	Micro- to Nano-Photonics III, ROMOPTO 2012, 10^{th} International Conference on Optics, 3-6 September, Bucharest, Romania, presentation II.P.1	Prezentare poster http://romopto.inflpr.ro/ ProgramFinal.pdf
5.	G. Salamu, F. Voicu, N. Pavel, T. Dascalu, F. Jipa, and M. Zamfirescu, “Diode-pumped laser emission in femtosecond-laser inscribed Nd:YAG waveguides”	International Conference "Modern Laser Applications" Third Edition, INDLAS 2013, 20-24 May 2013, Bran, Romania, presentation O1	Prezentare orala http://indlas.inflpr.ro/ INDLAS-Program.pdf
6.	N. Pavel, G. Salamu, F. Voicu, F. Jipa, and M. Zamfirescu, “Femtosecond-laser inscribed Nd:YAG waveguides. Realization and laser emission“	LPHYS’13: 22nd International Laser Physics Workshop, Prague, 15-19 July, 2013, presentation 4.1.3	Prezentare orala http://www.lasphys.com/ workshops/lasphys13/ program.pdf
7.	N. Pavel, G. Salamu, F. Jipa, and M. Zamfirescu, “Laser emission from diode-pumped Nd:YAG waveguides, realized by direct femtosecond-laser writing technique“	Advanced Solid State Lasers (ASSL) Congress, 27 October - 1 November 2013, Paris, France, presentation ATu2A.6	Prezentare orala http://www.osa.org/osaorg /media/osa.media/ Meetings/2013_Lasers_Abstracts.pdf?ext= .pdf

- La paginile 10-12 ale acestui raport sunt prezentate titlurile articolelor si sectiunea Acknowledgements, in care este specificata mentinea ca articolul/prezentarea a fost finantat/finantata din acest contract. Informatii suplimentare se gasesc in pagina web a proiectului: http://ecs.inflpr.ro/idei_npavel_36_2011-2014.html

BREVETE

Nr. crt.	Autori, titlu articol	Tip de brevet	Informatii
1.	T. Dascalu, N. Pavel, G. Salamu, O. Grigore, F. Voicu, M. Dinca, "Sistem laser monolitic, compozit si compact cu livrare simultana a doua fascicule laser"	National	Cerere depusa la OSIM Numar aplicatie A-100417 / 03.05.2013.

IOP PUBLISHING LASER PHYSICS LETTERS
Laser Phys. Lett. **10** (2013) 095802 (5pp) doi:10.1088/1612-2011/10/9/095802

LETTER

Efficient laser emission in diode-pumped Nd:YAG buried waveguides realized by direct femtosecond-laser writing

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Abstract
Laser emission at 1.06 and 1.3 μm under pumping with diode lasers was obtained from buried waveguides that were realized in a 0.7 at.% Nd:YAG single crystal by direct writing with a femtosecond laser. A depressed circular waveguide with a diameter of 110 μm yielded laser pulses at 1.06 μm with an energy of 1.4 mJ under the pump with pulses of 9.1 mJ energy at 807 nm; in continuous-wave operation, an output power of 0.54 W with optical to optical efficiency of 0.14 was achieved. Emission at 1.3 μm is demonstrated for the first time from such waveguides, with an energy of 0.4 mJ per pulse. Results for laser emission in other depressed cladding types and two-line-type waveguides are discussed.

(Some figures may appear in colour only in the online journal)

1. Introduction

Controllable modification of the optical properties of a dielectric material enables realization of various micro-optical devices. Among these devices, waveguide lasers are of special interest in optoelectronics due to their compact dimensions, low threshold of emission and good output performance [1]. Optical waveguides can be fabricated in an existing host by different methods, such as ion beam or proton irradiation [2], optical writing with a femtosecond (fs) laser [3–5] or a

for light propagation. The second type of writing damages the material inside the track and causes a stress-induced refractive index change in the adjacent region; in this case the light is guided in between two tracks.

The second inscribing technique was used to obtain double-line (or double-wall) waveguides in various laser media, such as Nd:YAG [5, 7, 8], Nd-vanadates [9, 10] or Yb:YAG [11]. Furthermore, a pump with a tunable Ti:sapphire laser was employed to demonstrate continuous-wave (cw)

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realization of laser emission with increased performance.

Acknowledgments

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Romanian Reports in Physics, Vol. 65, No. 3, P. 943–953, 2013

Dedicated to Professor Valentin I. Vlad's 70th Anniversary

LASER EMISSION IN DIODE-PUMPED Nd:YAG SINGLE-CRYSTAL WAVEGUIDES REALIZED BY DIRECT FEMTOSECOND-LASER WRITING TECHNIQUE

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Abstract. Buried waveguides have been realized in a 0.7 at.% Nd:YAG single crystal using the direct-writing technique with a femtosecond laser. Efficient laser emission at 1.06 and 1.32 μm is demonstrated and laser action at 0.94 μm is obtained using the pump with fiber-coupled diode laser at 807 nm, the first demonstration of such devices.

Key words: lasers, solid-state, lasers, diode-pumped, lasers, neodymium, pumping, optical waveguides.

1. INTRODUCTION

The waveguide lasers [1] are of special interest in optoelectronics due to their compact dimensions, low threshold of emission and good output performances. Such optical devices can be fabricated in an existing host by various methods, like thermal ion indiffusion [2], ion exchange [3] or proton exchange [4], proton or ion beam irradiation [5, 6], or by direct writing with a femtosecond (fs) laser [7-9]. Using the direct fs-laser writing technique, two types of tracks can be realized in a host, depending on the material properties and on the fs-laser characteristics. The first kind is specific to glasses and $LiNbO_3$ and consists of a single line; this method provides a track that is used itself for light propagation. The second type of writing damages the material inside the inscribed track and causes a stress induced refractive index change in the adjacent region; in this case the light is guided in between two such tracks.

Double-wall waveguides were obtained in various laser media, such as Nd:YAG [9-11], Nd-vanadates [12, 13], Yb:YAG [14, 15], $Nd:Gd_3Ga_5O_{12}$ [16, 17], or $Pr:YLiF_4$ (Pr:YLF) [18]. The pump with a Ti:sapphire laser was employed to

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conditions could improve the laser performances at this wavelength of emission.

3. CONCLUSIONS

In conclusion, in this work we have reported on realization of two-wall type and buried depressed waveguides in 0.7-at.% Nd:YAG crystal by direct inscribing using the fs-laser technique. Laser emission on the four-level 1.06 and 1.32 wavelengths was obtained under the pump with a fiber-coupled diode laser at 807 nm. Laser pulses at 1.06 μm with 1.8 mJ energy (optical efficiency of 0.20) and cw output power of 0.54 W for 3.8 W incident pump power were measured from a 120 μm diameter buried depressed waveguide. Also, this device outputted laser pulses at 1.32 μm with 0.4 mJ energy. A two-wall waveguide yielded laser pulses at 1.06 and at 1.32 μm with 0.92 and 0.40 mJ energy, respectively. Laser action at 946 nm was observed under quasi-cw pumping. Further works will consider improvement of the writing technique and obtaining of laser emission with increased performances, as well as realization of this kind of laser waveguides in other Nd-based laser media.

Acknowledgments. This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS - UEFISCDI, project number PN-II-ID-PCE-2011-3-0363.

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IOP PUBLISHING LASER PHYSICS LETTERS
Laser Phys. Lett. **10** (2013) 055804 (5pp) doi:10.1088/1612-2011/10/5/055804

LETTER

Novel laterally pumped by prism laser configuration for compact solid-state lasers

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Abstract

We propose a new laser configuration in which the pump radiation is coupled into the laser crystal through a prism. The laser medium is square shaped and the prism is attached on one of its lateral sides, near one of the crystal extremities. The diode-laser fiber end is placed close to the prism hypotenuse, the pump radiation is coupled into the laser crystal through the opposite surface of the prism and propagates into the crystal through total internal reflections. This laser geometry is simple to align and permits the realization of compact diode-pumped laser systems, as well as power scaling. A diode-pumped Nd:YAG laser yielding pulses of 2.1 mJ energy under a pump with pulses of 9.9 mJ is demonstrated. The laser slope efficiency is 0.22. Furthermore, this geometry enables one to obtain passively Q-switched lasers with the saturable absorber crystal placed between the resonator high-reflectivity mirror and the laser crystal. A Nd:YAG laser, passively Q-switched by a Cr^{4+}:YAG crystal with initial transmission $T_0 = 0.90$, delivering laser output with a pulsed energy of 93 μJ, a duration of 26 ns and a pump threshold of 1.9 mJ, is realized in order to prove the concept.

(Some figures may appear in colour only in the online journal)

1. Introduction

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The laterally pumped by prism geometry proposed in this work can improve the compactness of the laser (because the coupling optics between the fiber and Nd:YAG is removed) and it is easier to align as only one optical element (i.e. the prism) is necessary. Furthermore, the Cr^{4+}:YAG SA crystal can be placed between the HRM of the resonator and Nd:YAG, where the laser beam is more intense. This kind of laser can also be a solution for a spark plug with applications in the automotive industry [27].

We perform preliminary experiments in order to prove the functionality of this new design. Thus, when a Cr^{4+}:YAG SA with initial transmission $T_0 = 0.90$ was placed as in figure 1(b), between uncoated Nd:YAG-1 and an OCM with transmission $T = 0.25$, the laser emitted pulses with energy of 109 μJ and 32 ns duration. The pump pulse energy was 3.9 mJ. On the other hand, when the Cr^{4+}:YAG crystal was moved between HRM and Nd:YAG-1 (the dashed position of figure 1(b)) the characteristics of the Q-switch laser pulse were the same, but the energy of the pump pulse decreased at 3.0 mJ. Similar behavior was observed

in a small volume and short length parts, which yields a very good overlap of the laser beam with the pumped volume of

this statement. The laser outputs pulses with 93 μJ energy and duration of 26 ns. A decrease of the pump energy from 4.1 mJ to 1.9 mJ was observed when the Cr^{4+}:YAG crystal was moved from its classical position between Nd:YAG and the output mirror to a position between the resonator high-reflectivity mirror and the laser crystal. We believe that such a laser could find applications in the automotive industry.

Acknowledgments

This work was financed by the Romanian National Authority for Scientific Research, CNDI-UEFISCDI, project number 58/2012 (PN-II-PT-PCCA-2011-3.2-1040) and partially supported by projects IDEI 36/2011 (PN-II-ID-PCE-2011-3-0363) and IDEI 37/2011 (PN-II-ID-PCE-2011-3-0801).

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Efficient, simultaneous dual-wavelength emission at 1.06 and 1.34 µm in Nd:$GdVO_4$ laser crystal

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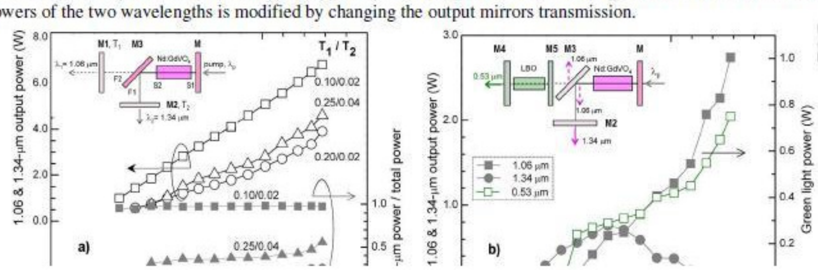
The operation of a laser medium simultaneously at two wavelength of emission has applications in medicine, optical communications, holographic interferometer, environmental monitoring, or generation of THz radiation. The first demonstration of a diode-pumped solid-state laser with simultaneous dual-wavelength emission, at 1064 and 1342 nm was made in a Nd:YVO_4 laser crystal [1]. The technique used a linear resonator with two- or three-output mirrors. Based on the same approach, simultaneous emission at 1.06 and 1.3 µm was obtained in various active media, like Nd:YAG, Nd:YAP, Nd:YVO_4, or Nd:$LuVO_4$ [2]. A second design employs distinct resonators, one for each of the emitted wavelength. Such an arrangement was used to demonstrate laser emission at 0.9 and 1.06 µm in Nd-laser crystals [3], or at 1.06 and 1.34 µm in Nd:YVO_4 [4].

In this work we describe efficient, simultaneous dual-wavelength laser emission at 1.06 and 1.34 µm in Nd:$GdVO_4$ using distinct, coupled resonators. A Nd:$GdVO_4$ laser that oscillates simultaneously at the two fundamental wavelengths and that generates also green light at 0.53 µm is realized for the first time.

The laser media is an a-cut, 10-mm thick, 0.27-at.% Nd:$GdVO_4$ crystal. The pump is made at 808 nm (λ_p) with fiber-coupled diode lasers (diameter ϕ= 800 µm, NA= 0.22). The fiber end is imaged into Nd:$GdVO_4$ to a 1:1 ratio. A linear resonator (output mirror M1 with transmission T_1) is used for emission at 1.06 µm, the laser oscillation at 1.34 µm is achieved with an L-type resonator (output mirror M2 with T_2), and the ratio between the powers of the two wavelengths is modified by changing the output mirrors transmission.



the total output power was obtained in comparison with the 808-nm pump, into the highly absorbing $^4F_{5/2}$ level.

A modified set-up (inset of Fig. 1b) was used in order to generate green light at 0.53 µm, by intra-cavity frequency doubling of the 1.06 µm wavelength with a LiB_3O_5 nonlinear crystal. For an absorbed power of 7.0 W at 808 nm, the laser generates 0.3 W of green light, and outputs simultaneously 0.64 W at 1.06 µm and 0.76 W at 1.34 µm (Fig. 1b). For the maximum absorbed pump power of 12.9 W, output powers of 0.74 W at 0.53 µm, 2.7 W at 1.06 µm and 0.15 W at 1.34 µm were measured. This approach opens the possibility to build continuous-wave diode-pumped solid-state lasers that generates simultaneously two beams into the visible spectrum.

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Best Poster SPIE Award

Generation of High-Peak Power 532-nm Green Pulses from Composite, All-Ceramics, Passively Q-switched Nd:YAG/Cr^{4+}:YAG Laser

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ABSTRACT

Laser pulses at 1.06 μm with 2.5-mJ energy and 3.1-MW peak power have been obtained from a composite, all-poly-crystalline ceramics, passively Q-switched 1.1-at.% Nd:YAG/Cr^{4+}:YAG laser that was quasi-continuous-wave pumped with diode lasers. Single-pass frequency doubling with LiB_3O_5 nonlinear crystal at room temperature yielded green laser pulses at 532 nm with energy of 0.36-mJ and 0.45-MW peak power; the infrared-to-green conversion efficiency was 0.27.

Keywords: Lasers, neodymium; Diode-pumped lasers; Q-switching; Harmonic generation.

1. INTRODUCTION

The passive Q-switching technique yields lower output performances compared to electro-optic or acousto-optic Q-switched lasers, but presents various others advantages, such as simple design, good efficiency and reliability, compactness, or low cost. This method yields laser pulses that are of interest for scientific, medical and industrial applications that do not require very high (better than microseconds range) temporal accuracy. The first continuous-wave (cw) diode end-pumped Nd:YAG laser, passively Q-switched by Cr^{4+}:YAG saturable absorber (SA) crystal, was made of a short piece of Nd:YAG crystal bonded to a thin Cr^{4+}:YAG SA crystal, and delivered laser pulses with 11-μJ energy (E_p) and 337-ps duration (t_p), at 6-kHz repetition rate [1]. A passively Q-switched Nd:YAG-Cr^{4+}:YAG laser that was build of discrete elements and that yielded pulses with energy E_p= 100 μJ and duration t_p= 36 ns at 15-kHz repetition rate was demonstrated later [2]. Furthermore, side-pumping geometry was employed to realize a Nd:YAG-Cr^{4+}:YAG laser with high pulse energy of 3.4 mJ, long 99-ns duration at 2.2-kHz repetition rate [3].

Various passively Q-switched Nd lasers were developed. A Nd:YAG-Cr^{4+}:YAG microchip laser outputted laser pulses at 946 nm with energy E_p= 23 μJ and duration t_p= 6.3 ns (peak power P_p= 3.7 kW) [4]. This kind of laser is a good device for laser range finding applications. Passively Q-switched lasers at 1.34 μm were developed by using V:YAG SA crystal [5, 6]. On the other hand, the need for high-peak power laser pulses motivated investigations of various Nd:YAG-Cr^{4+}:YAG microchip lasers, and special attention was paid to the composite laser media. Thus, using a composite Nd:YAG/Cr^{4+}:YAG structure, the Q-switched laser pulse energy at 946 nm was increased at 2 mJ energy, with pulse duration of 14 ns (i.e. ~0.14-MW peak power) [7]. Laser pulses with energy up to E_p= 67.3 μJ and peak power of nearly 33 kW were obtained from Nd:YAG/Cr^{4+}:YAG composite structures [8, 9]. On the other hand, the laser pulse peak power at the fundamental wavelength (λ_{em}) was high enough for efficient generation of visible light. Green laser pulses at 532 nm ($\lambda_{2\omega}$) with 3.4-μJ energy were obtained from a passively Q-switched Nd:YAG-Cr^{4+}:YAG laser whose output was single-pass frequency doubled with a BiB_3O_6 (BiBO) nonlinear crystal [10].

Fig. 4 Energy of the green laser pulse and conversion efficiency versus radius of the 1.06-μm laser beam.

4. CONCLUSIONS

In conclusion, laser pulses at 1.06 μm with 2.5-mJ energy and 3.1-MW peak power were obtained from a composite, all-ceramics 1.1-at.% Nd:YAG/Cr^{4+}:YAG medium. Green laser pulses at 532 nm with 0.36-mJ energy and 0.45-MW peak power were achieved by single-pass frequency doubling of the fundamental wavelength with an LBO nonlinear crystal at room temperature. This is believed to be the first demonstration of such a compact laser system and offers a solution for realizing high-peak power laser pulses into visible and ultraviolet regions by single-pass nonlinear conversion.

ACKNOWLEDGEMENTS

This work was supported by the Romanian National Authority for Scientific Research, CNDI-UEFISCDI, project number 58/2012 (PN-II-PT-PCCA-2011-3.2-1040) and project IDEI 36/2011 (PN-II-ID-PCE-2011-3-0363).

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TUESDAY, OCTOBER 29, 2013

ATu2A. Planar Waveguide and Hybrid Structure
Presider(s): Kenneth Schepler (US Air Force)
10:45 AM - 12:25 PM; LA SEINE A & B

View Session Details | Include All in Itinerary

12:01 PM - 12:13 PM ATu2A.6. Laser Emission from Diode-Pumped Nd:YAG Waveguides, Realized by Direct Femtosecond-Laser Writing Technique
Nicolaie I. Pavel; Gabriela Salamu; Florin Jipa; Marian Zamfirescu
View Presentation

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Laser Emission from Diode-Pumped Nd:YAG Waveguides, Realized by Direct Femtosecond-Laser Writing Technique

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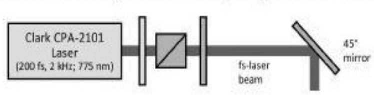
Abstract: Two-wall type and cylindrical-shaped depressed cladding waveguides were realized in Nd:YAG single crystal by direct writing with a femtosecond laser. Efficient laser emission at 1.06 and 1.32 μm is demonstrated under the pump with fiber-coupled diode laser.

OCIS codes: (140.0140) Lasers and laser optics; (140.3530) Lasers, neodymium; (230.7380) Waveguides, channelled.

The waveguide lasers [1] are of special interest in optoelectronics due to their compact dimensions, low threshold of emission and good output performances. Recently, such optical devices were successfully obtained by direct writing with a femtosecond (fs) laser. Double-wall waveguides were made in various laser media, such as Nd:YAG [2-4], Nd-vanadates [5], Yb:YAG [6], or Pr:YLF [7]. Furthermore, depressed cladding waveguides can be realized by inscribing many tracks around the perimeter of the desired configuration [8, 9]. This kind of waveguide has low propagation loss and possesses flexibility for different shapes and size, thus enabling good coupling to the waveguide of the pump beam. The output performances of various fs-laser written waveguide lasers were investigated mainly under the pump with Ti:sapphire laser. For example the pump with 2.25 W of power at 808 nm yielded 1.3 W output power at 1.06 μm with slope η_s= 0.54 from an Nd:YAG single-crystal waveguide [4]. The pump with a Ti:sapphire laser assures good coupling of the pump beam in the waveguide, but the final laser device can not be made compact. On the other hand, laser emission in Nd-based waveguides was realized only at 1.06 μm.

In this work we report on realization of double-wall waveguides and cylindrical depressed cladding waveguides in a Nd:YAG single crystal using the technique of direct writing with a fs laser, and we investigate performances of laser emission at 1.06 and 1.3 μm under the pump with a fiber-coupled diode laser at 807 nm.



bulk Nd:YAG and the influence of various parameters (pump-beam coupling efficiency, absorption efficiency, or losses) on the waveguide performances will be discussed. To the best authors knowledge this is the first report on laser emission at 1.3 μm from Nd:YAG waveguides obtained by direct fs-laser writing technique, while the laser performances at both 1.06 and 1.3 μm wavelengths are the highest realized under the pump with diode lasers. Further works will consider improvement of the writing technique, especially for the depressed cladding waveguides, and obtaining of laser emission with increased performances.

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