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The influence of distributed rare earth dopant on the performance of waveguide lasers fabricated by the femtosecond laser direct-write technique

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ABSTRACT

The development of an Yb-doped distributed Bragg reflector (DBR) waveguide laser fabricated in phosphate glass using the femtosecond laser direct-write technique is reported. The laser has the slope efficiency of 31% with the output power up to 81 mW at a pump power level of 378 mW. A theoretical model for the waveguide laser (WGL) is presented which gives emphasis to transverse integrals to investigate the energy distribution in a homogenously doped glass which is opposed to the fiber laser. The model was validated with experiments comparing a DBR WGL, and then used to study the influence of distributed rare earth dopants on the performance of such lasers. Approximately 15% of the pump power was absorbed by the doped “cladding” in the femtosecond laser inscribed Yb doped WGL case.

Keywords: Laser and laser optics, Glass waveguide, Laser theory, Ultrafast laser

1. INTRODUCTION

The femtosecond laser direct-write technique has attracted great interests since it firstly demonstrated in 1996 [1]. The focused femtosecond laser pulses can create a permanent refractive index modification inside bulk materials. This technique enables simple creation of compact 3D structures in transparent materials with greater flexibility than traditional fabrication methods involving ion exchange or photolithography. It has already been successfully utilized to fabricate optical devices, passive and active, in a variety of optical materials. Passive devices realized by this technique include waveguides [2], power splitters [3], couplers [4] and gratings [5]. Active devices, such as amplifiers and lasers, have been developed inside various host materials including many glasses and crystals. For example, both femtosecond laser written waveguide lasers with external optical feedback [6, 7] and monolithic distributed feedback (DFB) WGL [8] have been demonstrated.

As more femtosecond laser direct-written active devices become experimentally realized, a model for the WGL fabricated using femtosecond laser direct-write technique is very desirable for two reasons. Firstly the simulations can help to predict and optimize the devices’ performance which can reduce the development time and cost significantly. Secondly, a model can help to improve the physical insight on the WGL fabricated using the new technique by allowing us to carry out calculations and hypothetical experiments, which in many cases can be extremely difficult in laboratory conditions. To date, several models of femtosecond laser written waveguides in rare earth doped glass have been reported. Notably, a model was developed by Valles et al. to calculate the transmission loss and coupling loss of the ultrafast laser written waveguides in rare earth Yb codoped glass [9].

For conventional fiber lasers, the rare earth dopants are only distributed throughout the core. However, for femtosecond laser written waveguide lasers in which the dopants are distributed not just in the waveguide core but throughout the glass, including the surrounding unmodified glass, referred to as a doped “cladding” below. In the model for fiber lasers an effective overlap coefficient can be adopted to define the overlap between the pump and dopant profile [10, 11]. However, this coefficient is not suitable for WGL. Our model is based on a set of rate equations and takes into account the spatial integral between the pump/signal power and the dopant area. Although the model is not limited to
particular mirror geometry, we apply it to a DBR configuration, that is, a WGL with fiber Bragg gratings as reflection mirrors at both ends.

This paper is organized as follows. In Section 2, we present the experimental fabrication of the waveguides using femtosecond laser direct-write technique and the laser setup. In Section 3 we show the model of the WGL and validate it with the experimental results. Finally, some conclusions are given in Section 4.

2. EXPERIMENT

2.1 Waveguide fabrication

The regeneratively amplified Ti:sapphire laser had a 1 kHz repetition rate, 120 femtosecond pulse length, and operated at 800 nm. Waveguides were written in a “QX” phosphate glass (Kigre Inc.) doped with 9 wt%. The peak absorption of the glass is approximate 978 nm. The laser beam was focused at a depth of 170 µm below the surface of the glass sample by a 20× (NA 0.46) microscope objective. The beam was circularly polarized and focused into the glass through a slit with width of 500 µm.

The speed of the stage moved at a speed of 25 µm/s. The final length of the glass sample, after polishing, was 9.8 mm. The morphology of the waveguides was first checked with a differential interference contrast (DIC) microscope (Olympus IX81). Figure 1(a) shows a top view of a waveguide written with 1 µJ pulse energy and four writing passes. Figure 1(b) shows that the cross-sectional profile of the same waveguide is symmetric. The physical diameter of the waveguides is ~ 7 µm.

Waveguides were then characterized in terms of guided mode profile using the Pulnix TM-745E CCD camera. The mode profile of the waveguide is shown in Fig.2. The mode field diameter (MFD) measured was approximate 14.2 µm.

![Fig. 1(a) DIC top-view image of a waveguide (b) respective end-on cross section image](image)

2.2 Experimental setup

Pump light at 976 nm was launched into the Yb-doped waveguide through the high reflection grating. Two sets of detecting equipment were used to monitor the lasing output. A power meter was used to measure the output lasing power or the residual pump power. An optical spectrum analyzer with a resolution of 0.01 nm displayed the spectrum of the lasing signal. Short sections of graded index optical fiber (GIF625) were spliced to the fiber tips to better match the MFD of the waveguide to that of the coupling fiber. The coupling loss between the fibre and waveguide can be calculated as follows [12]:

![Fig.2 Guided mode profile of the waveguide](image)
\[ \delta = 1 - \frac{\sum I_j \sqrt{I_1 I_2}}{\sum I_1 \sum I_2} \]  

where \( I_j \) and \( I_2 \) are intensities measured at each point in the waveguide and fiber end cross section obtained from MFD images.

Fig. 3 Schematic of the DBR waveguide laser. HR-High Reflectivity grating. OC-Output Coupler grating. WDM-Wavelength-Division Multiplexer. OSA- Optical Spectrum Analyser.

### 3. THEORETICAL MODELING

#### 3.1 Rate equations

The Yb\(^{3+}\) energy level structure is simple, consisting of a ground state manifold, \( ^2F_{7/2} \), Stark-split into four sublevels and a exited-state manifold, \( ^2F_{5/2} \), Stark-split into three sublevels. Thus, excited state absorption (ESA) at both the pump and signal wavelengths is absent. The energy level of Yb\(^{3+}\) in phosphate glass is shown in Fig. 4.

The theoretical model considers a homogeneously broadened two-level system. All other sub-levels are assumed to be unpopulated because Yb ions emission from these levels takes place by a fast non-radiative transition. At stable state, the rate equations describe the effects of absorption, stimulated emission and propagation losses of the laser system are given by [13]

\[ \frac{dP_p^+}{dz} = \sigma_{\phi} P_p^+(z) \int_0^L i_p(\tau,\phi)n_p(r,\phi,z)rd\phi - \sigma_{\phi} P_p^+(z) \int_0^L i_p(\tau,\phi)(n_p(r,\phi,z) - n_p(r,\phi,z))rd\phi - \alpha P_p^+(z) \]  

\[ \frac{dP_s^+}{dz} = \sigma_{\phi} P_s^+(z) \int_0^L i_s(\tau,\phi)n_s(r,\phi,z)rd\phi - \sigma_{\phi} P_s^+(z) \int_0^L i_s(\tau,\phi)(n_s(r,\phi,z) - n_s(r,\phi,z))rd\phi - \alpha P_s^+(z) \]  

![Fig. 4 Energy level of Yb3+ in phosphate glass (All energy are given in cm-1)](image-url)
where \( n_i \) is the Yb ion density which is a constant because the glass is doped uniformly; \( n_2 \) is the upper lasing level population density with fluorescence lifetime \( \tau \). \( n_2 \) varies radially along the waveguide. By defining \( n_i=n_1+n_2 \), \( n_1 \) is eliminated from the equations. \( P_{sp} \) is the pump and signal’s total power at position \( z \) along the waveguide. Each beam is travelling either in the forward or backward direction represented by the plus and minus superscripts. \( \sigma_p \) and \( \sigma_a \) are the emission and absorption cross section respectively. The emission and absorption cross section varies with wavelength, but here they can be assumed to be constant because the pump and signal band widths are very narrow. \( \alpha_p \) and \( \alpha_a \) are the scattering loss of the pump and signal. \( \nu_p \) and \( \nu_i \) is pump and signal frequency. \( h \) is Planck’s constant and \( c \) the speed of light in vacuum. \( i_s, i_p \) represent the normalized optical intensity of pump and signal that is a function of radial and angle.

A Gaussian approximation to the optical mode is assumed to be \( i=(1/\pi w^2) \exp(-r^2/w^2) \).

The equations (2) are to be solved subject to the boundary conditions:

\[
P_r^s(L) = P_r^s(L) \cdot R_{\text{in}}, \quad \text{(3-a)}
\]

\[
P_r^s(0) = P_r^s(0) \cdot R_{\text{ref}}^p, \quad \text{(3-b)}
\]

\[
P_r^s(0) = P_r^s(0) \cdot R_{\text{ref}}^p + P(0), \quad \text{(3-c)}
\]

\[
P_r^s(L) = P_r^s(L) \cdot R_{\text{ref}}^p + P(L), \quad \text{(3-d)}
\]

where \( R_{\text{ref}}^p \) and \( R_{\text{ref}}^s \) are the reflectivity of the Bragg reflectors at \( z=0 \) and \( z=L \) for the pump and signal respectively. The spontaneous emission into the propagating laser mode is used to initiate the lasing process [14]. Equations (2) were solved using the fourth-order Runge-Kutta method. The initial condition is supposed at \( z=0 \) to start the differential equations to be integrated. With the launched pump power, \( P_r^s(0) \), fixed the signal power is varied along the waveguide. Considering the boundary conditions at \( z=0 \) and \( z=L \), the integration process was iterated until convergence was obtained.

### 3.2 Comparison between the model and experimental results

The simulated results were compared with the experimental results of a DBR WGL in order to validate the model. Rate equations were solved with the parameters listed in Table 1. Most parameters used in the modeling were set according to the glass manufacturer’s data.

The output signal measured in the experiment was centred at 1031.7 nm shown in Fig. 5(a). The output power with respect to the pump power obtained from experiments (circles) and modeling (red line) is illustrated in Fig. 5(b). The output power increased linearly as the pump power increased. The threshold of the waveguide laser is approximately 112.5 mW. The experimental data shows that the slope efficiency of the waveguide laser was 31%. Figure 5(b) shows that the modeling results (red line) agree with the experimental data (black dots) up to a pump power of 250 mW, above which the modeling and experimental results deviate from one another. This kind of deviation was reported by Florea et al. as well in Yb doped WGL with doped concentration as high as 12wt. % [15]. The calculated and measured lasing threshold values reported by Florea et al. agree quite closely, while the slope efficiency predictions were not accurate. Here we attribute this deviation mainly to the cooperative luminescence process of Yb ions in the glass [16]. This process consumes two Yb ions from their upper energy levels by emitting a single photon with twice the energy of the laser signal and the rate of this process is strongly dependent on the pump level. In experiment the blue luminescence was observed by eyes. However, this process was neglected in the model for simplicity. In addition, at higher pump power the effective lifetime of the upper level of Yb ions is quenched [17] which leads to a decrease of the output power which was also not accounted for. The close match, at moderate pump powers, between the modeled and experimental results validates our approach is able to predict the laser output.
Table 1. Parameters used for the Yb$^{3+}$-doped DBR waveguide laser model

<table>
<thead>
<tr>
<th>$\lambda_p$</th>
<th>$\lambda_s$</th>
<th>$\sigma_{ap}$</th>
<th>$\sigma_{ep}$</th>
<th>$\sigma_{as}$</th>
<th>$\sigma_{es}$</th>
<th>$\tau$</th>
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</thead>
<tbody>
<tr>
<td>(nm)</td>
<td>(nm)</td>
<td>(10$^{-20}$ cm$^2$)</td>
<td>(10$^{-20}$ cm$^2$)</td>
<td>(10$^{-20}$ cm$^2$)</td>
<td>(10$^{-20}$ cm$^2$)</td>
<td>(ms)</td>
</tr>
<tr>
<td>976</td>
<td>1031.7</td>
<td>1.07</td>
<td>0.9</td>
<td>0.01</td>
<td>0.35</td>
<td>2</td>
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</table>

Fig. 5(a) Spectrum of the output signal (b) Experimental (black dots) and theoretical (red line) output power versus pump power of the DBR waveguide laser.

3.3 Modeling results

The model is used to study the influence of the doped cladding on the output power of the waveguide laser. Figure 6 shows the modeled output power with respect to the incident pump power of the DBR WGL for both the fully doped and inhomogeneously doped case, the latter with a doped radius of 10 μm corresponding to a maximum in modeled output power. With the doped radius of 10 μm where the overlap between the pump profile and the dopant profile is most optimized, the output can reach the maximum. The refractive index contrast and the length were assumed to be 1.6×10$^{-3}$ and 9.8 mm corresponding to the experiment. When the glass is inhomogeneously doped with radius of 10 μm, the threshold reduced to 85 mW with maximum output power of 117 mW. It can be calculated that approximately 15% pump power was lost in the doped cladding.

Fig. 6 Output power versus pump power of the DBR waveguide laser

4. Conclusion

In conclusion we have presented the fabrication, characterization and theoretical modeling for DBR waveguide lasers fabricated using the femtosecond laser direct-write technique. The laser threshold was ~112 mW with a maximum output
power of 81 mW at a pump power level of 378 mW. We also developed the numerical model which accounts for the presence of a homogeneously distributed rare earth dopant. The model was validated by analyzing an ultrafast laser inscribed waveguide laser. This model enables us to predict the laser performance such as the threshold and output. It also helps to study the influence of the doped cladding on the laser performance. Approximately 15% of the pump power was lost in the doped cladding of the Yb doped DBR WGL. However, the improved overlap between the pump profile and dopant profile would increase the output power. Moreover, the model is not limited. It can be expanded to DBR WGLs of other kinds of rare earth dopants or symmetric structures in order to provide reasonable predictions and further design optimizations.

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REFERENCES


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Volume 8611
## Contents

ix  Conference Committee

### SESSION 1  MICRO AND NANO MANIPULATION OF CELLS, OPTICAL TRANSFECTION

<table>
<thead>
<tr>
<th>Paper ID</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8611 03</td>
<td>High-throughput optical injection of mammalian cells using a non-diffracting beam in a microfluidic platform [8611-2]</td>
<td>H. A. Rendall, R. F. Marchington, B. B. Praveen, Univ. of St. Andrews (United Kingdom); G. Bergmann, Friedrich-Schiller-Univ. Jena (Germany); Y. Arita, Univ. of St. Andrews (United Kingdom); A. Heisterkamp, Friedrich-Schiller-Univ. Jena (Germany); F. J. Gunn-Moore, K. Dholakia, Univ. of St. Andrews (United Kingdom)</td>
</tr>
<tr>
<td>8611 04</td>
<td>Femtosecond optical transfection as a tool for genetic manipulation of human embryonic stem cells [8611-3]</td>
<td>M. L. Torres-Mapa, Univ. of St. Andrews (United Kingdom); J. Gardner, H. Bradburn, J. King, Roslin Cellab (United Kingdom); K. Dholakia, F. Gunn-Moore, Univ. of St. Andrews (United Kingdom)</td>
</tr>
</tbody>
</table>

### SESSION 2  TISSUE AND SURGICAL APPLICATIONS OF ULTRASHORT PULSE LASERS

<table>
<thead>
<tr>
<th>Paper ID</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8611 0A</td>
<td>Pump-probe investigation of fs-LIOB in water by simultaneous spatial and temporal focusing [8611-9]</td>
<td>R. Kammel, R. Ackermann, Friedrich-Schiller-Univ. Jena (Germany); A. Tünnermann, S. Nolte, Friedrich-Schiller-Univ. Jena (Germany) and Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)</td>
</tr>
</tbody>
</table>

### SESSION 3  NOVEL MEDICAL APPLICATIONS OF ULTRAFAST LASERS

<table>
<thead>
<tr>
<th>Paper ID</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8611 0D</td>
<td>Harmonic nanoparticles for nonlinear bio-imaging and detection (Invited Paper) [8611-12]</td>
<td>L. Bonacina, T. Magouroux, A. Rogov, Univ. of Geneva (Switzerland); D. Staedler, Ecole Polytechnique Fédérale de Lausanne (Switzerland); C. Joulou, Univ. de Savoie (France); S. Schwung, FEE GmbH (Germany); S. Passemard, Ecole Polytechnique Fédérale de Lausanne (Switzerland); R. Le Dantec, Y. Mugnier, Univ. de Savoie (France); D. Rytz, FEE GmbH (Germany); S. Gerber-Lemaire, Ecole Polytechnique Fédérale de Lausanne (Switzerland); J.-P. Wolf, Univ. of Geneva (Switzerland)</td>
</tr>
<tr>
<td>8611 0F</td>
<td>Label free optimal dynamic discrimination of biological macromolecules [8611-14]</td>
<td>S. Afonina, A. Rondi, D. Kiselev, L. Bonacina, J. P. Wolf, Univ. of Geneva (Switzerland)</td>
</tr>
<tr>
<td>8611 0G</td>
<td>Femtosecond pumped lasing from the fluorescent protein DsRed in a one dimensional random cavity [8611-15]</td>
<td>T. M. Drane, H. Bach, M. Shapiro, V. Milner, The Univ. of British Columbia (Canada)</td>
</tr>
</tbody>
</table>
SESSION 4  ULTRAFAST LASER SOURCES FOR BIOMEDICAL USE

8611 0J  100-fs-level diode-pumped Yb-doped laser amplifiers [8611-18]
M. Delaigue, J. Pouysegur, S. Ricaud, C. Höninger, E. Mottay, Amplitude Systèmes (France)

8611 0K  A new small-package super-continuum light source for optical coherence tomography [8611-19]
S. Meissner, P. Cimalla, Technische Univ. Dresden (Germany); B. Fischer, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany); C. Taudt, T. Baselt, P. Hartmann, Westsächsische Hochschule Zwickau (Germany); E. Koch, Technische Univ. Dresden (Germany)

8611 0L  Defense of fake fingerprint attacks using a swept source laser optical coherence tomography setup [8611-20]
S. Meissner, Technische Univ. Dresden (Germany); R. Breithaupt, Bundesamt für Sicherheit in der Informationstechnik (Germany); E. Koch, Technische Univ. Dresden (Germany)

SESSION 5  ULTRAFAST LASER SOURCES AND INSTRUMENTATION

8611 0N  3D ultrafast laser scanner [8611-22]
A. Mahjoubfar, K. Goda, Univ. of California, Los Angeles (United States) and California NanoSystems Institute (United States); C. Wang, Univ. of California, Los Angeles (United States); A. Fard, Univ. of California, Los Angeles (United States) and California NanoSystems Institute (United States); J. Adam, Univ. of California, Los Angeles (United States); D. R. Gossett, California NanoSystems Institute (United States) and Univ. of California, Los Angeles (United States); D. Di Carlo, California NanoSystems Institute (United States) and Univ. of California, Los Angeles (United States); B. Jalali, Univ. of California, Los Angeles (United States) and California NanoSystems Institute (United States)

8611 0P  Simultaneous measurement of two ultrashort pulses at different wavelengths using double blind polarization-gate frequency-resolved optical gating [8611-24]
T. C. Wong, R. Trebino, Georgia Institute of Technology (United States)

8611 0Q  New, simplified algorithm for cross-correlation frequency resolved optical gating [8611-25]
D. J. Kane, Mesa Photonics, LLC (United States)

8611 0R  The coherent artifact in modern pulse measurement [8611-26]
M. Rhodes, Georgia Institute of Technology (United States); G. Steinmeyer, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany); J. Ratner, R. Trebino, Georgia Institute of Technology (United States)

8611 0S  Temporal self-reconstruction of few-cycle nondiffracting wavepackets [8611-27]
S. König, M. Bock, S. K. Das, A. Treffer, R. Grunwald, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany)
SESSION 6  ULTRAFAST LASER VOLUME STRUCTURING I

8611 OW  The influence of distributed rare earth dopant on the performance of waveguide lasers fabricated by the femtosecond laser direct-write technique [8611-31]
Y. Duan, A. McKay, P. Dekker, M. J. Steel, M. Withford, Macquarie Univ. (Australia)

SESSION 7  ULTRAFAST LASER VOLUME STRUCTURING II

8611 OY  The underlying structure of ultrashort pulse laser-induced nanogratings [8611-33]
F. Zimmermann, S. Richter, Friedrich-Schiller-Univ. Jena (Germany); A. Plech, Karlsruher Institut für Technologie (Germany); S. Döring, Friedrich-Schiller-Univ. Jena (Germany); M. Heinrich, Friedrich-Schiller-Univ. Jena (Germany) and CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); M. Steinert, Friedrich-Schiller-Univ. Jena (Germany); U. Peschel, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); E.-B. Kley, Friedrich-Schiller-Univ. Jena (Germany); A. Tünnermann, S. Nolte, Friedrich-Schiller-Univ. Jena (Germany) and Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

SESSION 8  ULTRAFAST LASER VOLUME STRUCTURING III

8611 11  Adaptive control of pulse front tilt, the quill effect and directional ultrafast laser writing [8611-36]
P. S. Salter, R. D. Simmonds, M. J. Booth, Univ. of Oxford (United Kingdom)

8611 12  Femtosecond laser ablation properties of transparent materials: impact of the laser process parameters on the machining throughput [8611-37]
V. V. Matylitsky, F. Hendricks, J. Aus der Au, High Q Laser GmbH (Austria)

8611 13  On the wavelength dependence of femtosecond laser interactions inside band gap solids [8611-38]
S. Leyder, D. Grojo, Ph. Delaporte, M. Lebugle, Lab. Lasers, Plasmas et Procédés Photoniques, CNRS, Aix-Marseille Univ. (France); W. Marine, CINAM, CNRS, Aix-Marseille Univ. (France); N. Sanner, M. Sentis, O. Utéza, Lab. Lasers, Plasmas et Procédés Photoniques, CNRS, Aix-Marseille Univ. (France)

SESSION 9  ULTRAFAST LASER MICROMACHINING I: FUNDAMENTALS: JOINT SESSION WITH CONFERENCES 8607 AND 8611

8611 17  Time-resolved spectroscopy characterization of femtosecond fiber laser induced plasma [8611-42]
H. Huang, L.-M. Yang, J. Liu, PolarOnyx, Inc. (United States)

8611 18  Study on the influence of repetition rate and pulse duration on ablation efficiency using a new generation of high power ytterbium doped fiber ultrafast laser [8611-43]
J. Lopez, CELIA, CNRS/CEA, Univ. Bordeaux 1 (France); R. Torres, ALPhANOV (France); Y. Zaouter, Amplitude Systèmes (France); P. Georges, M. Hanna, Institut Optique Graduate School (France); E. Mottay, Amplitude Systèmes (France); R. Kling, ALPhANOV (France)
SESSION 10  ULTRAFAST LASER MICROMACHINING II: FUNDAMENTALS: JOINT SESSION WITH CONFERENCES 8607 AND 8611

8611 1A  Micro-structuring of thin titanium films with ultrashort laser pulses [8611-45]
R. Moser, T. Gschwilm, A. Zacherle, G. Heise, H. P. Huber, Munich Univ. of Applied Sciences (Germany); G. Marowsky, Laser Lab. Göttingen (Germany)

8611 1B  Transient temperature modeling and shock wave observation in confined laser ablation of thin molybdenum films [8611-46]
M. Domke, J. Sotrop, S. Rapp, M. Börger, D. Felsl, H. P. Huber, Munich Univ. of Applied Sciences (Germany)

SESSION 11  ULTRAFAST LASER MICROMACHINING III: JOINT SESSION WITH CONFERENCES 8607 AND 8611

8611 1C  Ultrastable bonding of glass with femtosecond laser bursts [8611-47]
S. Richter, F. Zimmermann, S. Döring, Friedrich-Schiller-Universität Jena (Germany); A. Tünnermann, S. Nolte, Friedrich-Schiller-Universität Jena (Germany) and Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

SESSION 12  ULTRAFAST LASER MICROMACHINING IV: JOINT SESSION WITH CONFERENCES 8607 AND 8611

8611 1D  Influence of ambient pressure on the hole formation process in ultrashort pulse laser deep drilling [8611-48]
S. Döring, S. Richter, T. Ullsperger, Friedrich-Schiller-Universität Jena (Germany); A. Tünnermann, S. Nolte, Friedrich-Schiller-Universität Jena (Germany) and Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

POSTER SESSION

8611 1H  Laser time-of-flight measurement based on multi-channel time delay estimation [8611-52]
C. Li, Q. Chen, G. Gu, T. Man, Nanjing Univ. of Science and Technology (China)

8611 1I  Characterization of femtosecond laser filament-fringes in titanium [8611-54]
Md. S. Ahsan, KAIST (Korea, Republic of) and Khulna Univ. (Bangladesh); F. Dewanda, KAIST (Korea, Republic of); F. Ahmed, M. B. G. Jun, Univ. of Victoria (Canada); M. S. Lee, KAIST (Korea, Republic of)

8611 1J  Liquid jet generated by thermocavitation bubbles within a droplet [8611-55]
J. P. Padilla-Martinez, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); D. Banks, Univ. of California, Riverside (United States); J. C. Ramirez-San-Juan, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); G. Aguilar, Univ. of California, Riverside (United States); R. Ramos-Garcia, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

8611 1M  Laser-induced structural modifications in glass using a femtosecond laser and a CO2 laser [8611-58]
T. Tamaki, S. Nakazumi, K. Nakamura, S. Ono, Nara National College of Technology (Japan)
Defect detection in laser powder deposition components by laser thermography and laser ultrasonic inspections [8611-59]
S. P. Santospirito, Kingston Computer Consultancy Ltd. (United Kingdom); R. Łopatka, Polkom Badania (Poland) and Warsaw Univ. of Technology (Poland); D. Cerniglia, Univ. degli Studi di Palermo (Italy); K. Styk, B. Luo, Kingston Computer Consultancy Ltd. (United Kingdom); D. Panggabean, J. Rudlin, TWI Ltd. (United Kingdom)

Author Index
Conference Committee

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1. Micro and Nano Manipulation of Cells, Optical Transfection
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2. Tissue and Surgical Applications of Ultrashort Pulse Lasers
   Michel Meunier, École Polytechnique de Montréal (Canada)
3 Novel Medical Applications of Ultrafast Lasers
Alexander Heisterkamp, Friedrich-Schiller-Universität Jena (Germany)

4 Ultrafast Laser Sources for Biomedical Use
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5 Ultrafast Laser Sources and Instrumentation
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6 Ultrafast Laser Volume Structuring I
Peter R. Herman, University of Toronto (Canada)

7 Ultrafast Laser Volume Structuring II
Peter R. Herman, University of Toronto (Canada)

8 Ultrafast Laser Volume Structuring III
Rafael Piestun, University of Colorado at Boulder (United States)

9 Ultrafast Laser Micromachining I: Fundamentals: Joint Session with Conferences 8607 and 8611
Yong Feng Lu, University of Nebraska-Lincoln (United States)

10 Ultrafast Laser Micromachining II: Fundamentals: Joint Session with Conferences 8607 and 8611
Stefan Nolte, Friedrich-Schiller-Universität Jena (Germany)

11 Ultrafast Laser Micromachining III: Joint Session with Conferences 8607 and 8611
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12 Ultrafast Laser Micromachining IV: Joint Session with Conferences 8607 and 8611
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