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HORIZONTAL DRILLING ENGINEERING

THEORY, METHODS AND APPLICATIONS

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Horizontal Drilling Engineering - Theory, Methods and Applications

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Edited by **M. S. Chauhan**

ISBN: 978-1-68117-399-3

Library of Congress Control Number: 2015941589

www.scitusacademics.com
Box No. 4766, 616 Corporate Way,
Suite 2, Valley Cottage,
NY 10989

Printed in United States of America on Acid Free Paper ∞

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Preface

Drilling engineering is a challenging discipline in the oil patch. It goes beyond what is found in textbooks. The technological advances in the past two decades have been very significant. These advances have allowed the oil industry worldwide to economically and successfully exploit oil and gas fields that may have not been possible before. The fundamentals of fluid mechanics and solid mechanics, along with the basic scientific concepts of chemistry, form the basis of drilling engineering. The rewards and successes of drilling projects are predicated on the ability of the drilling engineer who fully understands all the engineering aspects and equipment required to drill a usable hole at the lowest dollar per foot, in vertical well drilling, or at the highest equivalent barrel of oil per foot in horizontal/multilateral well drilling. Horizontal Drilling Engineering book gives the fundamentals and field practices involved in horizontal drilling operations. Key Features & Benefits: This textbook is an excellent resource for drilling engineers, directional drillers, drilling supervisors and managers, and petroleum engineering students.

Editor

Contents

Chapter 1

Nanofabrication with Pulsed Lasers

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ABSTRACT

An overview of pulsed laser-assisted methods for nanofabrication, which are currently developed in our Institute (LP3), is presented.

The methods compass a variety of possibilities for material nanostructuring offered by laser–matter interactions and imply either the nanostructuring of the laser-illuminated surface itself, as in cases of direct laser ablation or laser plasma-assisted treatment of semiconductors to form light-absorbing and light-emitting nano-architectures, as well as periodic nanoarrays, or laser-assisted production of nanoclusters and their controlled growth in gaseous or liquid medium to form nanostructured films or colloidal nanoparticles. Nanomaterials synthesized by laser-assisted methods have a variety of unique properties, not reproducible by any other route, and are of importance for photovoltaics, optoelectronics, biological sensing, imaging and therapeutics.

INTRODUCTION

When nanostructured, many materials start to exhibit new optical properties making them unique for a plethora of applications. In particular, despite small and indirect band gaps in the bulk state, the nanostructured IV group semiconductors (e.g. Si, Ge) become efficient size-dependent emitters in the visible light range [1,2], but also can work as photosensitizers to generate singlet oxygen under photoexcitation [3,4]. Another prominent example relates to noble metal nanostructures, which provide a number of unique plasmonic effects, including size-dependent absorption peaks [5,6], drastic local electric field enhancement [7,8], resolution beyond the diffraction limit [9], nanotrapping[10] etc. These new properties of emerging nanomaterials appear to be extremely promising for photovoltaics and optoelectronics, as well as for biological sensing, imaging and therapeutics.

The employment of pulsed lasers offers a novel unique tool for nanofabrication [11]. When focused on the surface of a solid target, pulsed laser radiation causes a variety of effects, including heating, melting and finally ablation of the target and such processes can lead to an efficient material nanostructuring, as shown in Fig. 1. First, the laser-assisted removal of material from the irradiated spot can result in a spontaneous formation of variety of periodic microand nanoarchitectures within this spot [12-16]. Second, laser ablation of material from a solid target leads to the production of nanoclusters [17-20]. When produced in gaseous environment or in vacuum, these nanoclusters can then be deposited on a substrate yielding to the formation of a nanostructured film [17,21-24]. When produced in liquid environment, the nanoclusters can be released into the liquid forming a colloidal nanoparticle solution [25-32]. In all cases, properties of formed nanostructures can be unique and not reproducible by any other route [27-33]. As an example, the fabrication of nanoparticles in aqueous solutions does not require any chemical reducing agent, which conditions unique surface chemistry and purity of produced nanomaterials [28,29]. Furthermore, when synthesized in clean, biocompatible environment, laser-synthesized nanomaterials are exempt of any residual toxicity that is typical for chemically synthesized nanoparticles [32,33].

In this paper, we review laser-assisted technologies, developed by LP3 members, which are now available in our Institute.

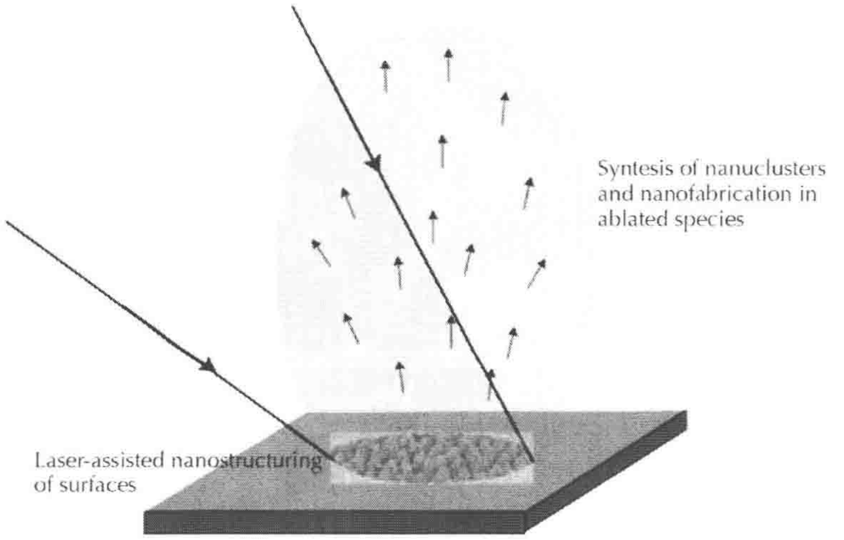

Figure 1: Schematics of laser–target interaction and material nanostructuring.

LASER-ASSISTED NANOSTRUCTURING OF SURFACES

Properties of laser-materials interaction are known to be strongly dependent on parameters of laser radiation. Among these parameters, the wavelength and pulse length are especially important to determine the efficiency of radiation absorption, dynamics of plasma plume expansion and nanoclustering [11]. Ultraviolet, visible and near-infrared lasers are normally considered as most adequate for laser ablative tasks. Indeed, most industrially important materials efficiently absorb laser radiation in the spectral range of 200–1,000 nm, yielding to material ablation and nanostructuring. In addition, radiation of UV and visible lasers is relatively transparent to laser plasma, which minimizes laser beam distortions and power losses before reaching the target. In contrast, the interaction of infrared radiation (1–11 μm) with materials is characterized by a strong energy absorption by plasma itself, which completely changes conditions of nanostructuring. The pulse length is another important parameter in laser–matter interaction. Micro- and nanosecond laser–matter interactions are typically associated with long ablation regime, in which the ablation process takes place during the laser pulse itself. In contrast, pico- and femtosecond lasers offer short ablation regimes, in which moments of radiation absorption and material ablation are temporally separated. Although multi-pulse laser ablation from the target surface is always accompanied by the formation of micro- and nanoscale features and periodic structures [12-16,34], properties of these features strongly depend on the wavelength and pulse length. Therefore, depending on the task, one can select appropriate radiation parameters to condition the ablation regime and obtain prescribed properties of laser-synthesized nanostructures. Below, we give several examples of laser-assisted methodologies to fabricate nanostructures within the irradiation spot.

Femtosecond Laser Ablation of Si: Formation of Black Si for Photovoltaics Applications

It is accepted that femtosecond pulses give at least two major advantages to micromachining compared to nanosecond and longer pulses [35,36]: (1) the reduction of the pulse energy which is necessary to induce ablation for fixed laser wavelength and focussing conditions and (2) a significant reduction or complete removal of heat-affected zone (HAZ) and, as consequence, the improvement of the contour sharpness for the laser-processed structures. The second advantage is a direct consequence of the pulse being shorter than the heat diffusion time, given by the phonon transport. As in the case of nanosecond- and microsecond laser ablation, multi-pulse femtosecond ablation leads to a spontaneous formation of nanoarchitectures [14,37-40]. However, in contrast to long ablation, the fs regime is characterized by the absence of target melting effects, yielding to the formation of clean micro- and nanoscale features. In particular, using multi-pulse fs ablation of Si in the presence of SF_6 reactive gas, Mazur et al. [14,37] managed to fabricate extremely narrow micro-spikes within the irradiation spot, which are capable of efficiently absorbing light in the visible and infrared ranges. The efficient absorption of light exceeding 95% in the visible was attributed to a geometric multi-reflection effect offered by a unique spike-based structure, while the enhanced absorption in the infrared was explained by a sulphur doping [37]. Due to the wide-range absorption effect, the produced spike-based structure was called "black silicon" and was later used for the development of Si-based photodetectors. It is worth noting that such absorptive features cannot be reproduced by any alternative non-laser route. Other studies (see, e.g. [41]) reported the fabrication of nanostructured metal films exhibiting colours ("coloured metals") using similar fs ablation approach.

Our sub-project is devoted to the fabrication of "black silicon" structures for photovoltaics solar panel applications. The choice of photovoltaics as target application imposes new criteria on nanostructuring conditions. First, these applications require a high absorption mostly in the visible—near-IR range (300–1,000 nm), which enables us to exclude the necessity of using sulphur-based doping species. Second, these applications require uniform high-quality doping of nanostructured layers to maximize the photovoltage response. We succeeded in developing of a novel methodology to produce "black silicon" with such parameters, employing a Ti:Sapphire laser (wavelength 800 nm, pulse energy 5 mJ, repetition rate 1 kHz) [42]. In contrast to [14,37], we carry out multi-pulse laser processing in vacuum under the residual pressure of $(1–5) \times 10^{-5}$ mBar.

In addition, we avoid the doping procedure during the laser processing process and do it afterwards. To achieve a high quality doping of deep layers, the laser-structured samples are boron implanted by Plasma immersion (PULSION, BF3, 2 kV, 900°C, 30 min) and thermally annealed (TA). The junction depth obtained by this method is estimated to be about 150 nm, which is much shallower than the 3D laser structures; therefore, the junction follows the topography of the structures. Figure 2a demonstrates a silicon wafer surface after the laser processing and boron implantation procedure. Here, a rectangular area of 3×2 cm^2 is written by a programmed displacement with the speed of 150 μm/s of a femtosecond laser beam having the spot size of 35×35 μm^2. One can clearly see a black area on the silicon wafer associated with "black silicon".

As shown in Fig. 2b, the treated surface contains penguin-like nanospikes with the length of up to 10 μm and sub-μm lateral dimensions. Although the morphology of femtosecond laser-treated surface is rather different compared to narrow spike-like structures in [14,37], it is also characterized by an enhanced absorption in the visible range exceeding 90% (Fig. 2c). Depositing grating-like contacts on the top on the treated area, we were able to obtain the amplification of photocurrent by 50% compared to the untreated surface area. Such result was attributed to an enhanced absorption granted by the penguin-like structures, much larger surface of nanostructured silicon used for signal collection, and high quality of boron implantation offered by the post-ablation plasma implantation procedure. The fabricated structures are now actively tested as photovoltaics solar cells.

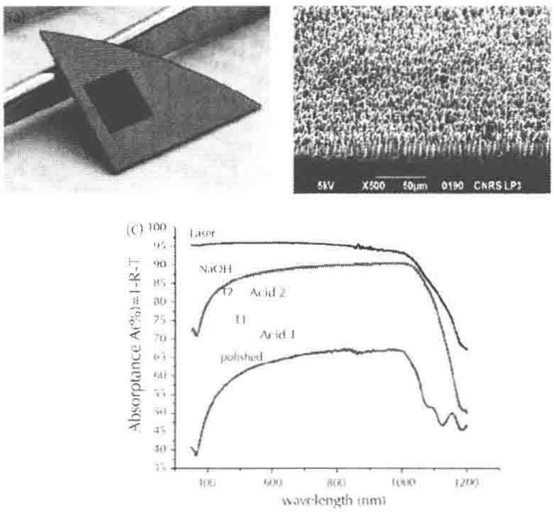

Figure 2: a Typical image of "black silicon" spot fabricated on a Si wafer by multi-pulse fs laser ablation in vacuum; b Typical scanning electron microscopy (*SEM*) image of penguin-like structure of black silicon; c Typical absorption spectra from "black silicon" and silicon treated by different methods.

Laser Plasma-assisted Nanostructuring of Surfaces

As we mentioned above, UV or ultrashort lasers contribute to a good radiation absorption by the target itself, while plasma remains relatively transparent to the incoming radiation. Such parameters ensure good quality of surface treatment in laser processing tasks. The plasma effect can be further minimized by reducing the pressure of the ambient gas. Depending on plasma plume size conditioned by the ambient gas pressure, the material can be re-deposited either within the irradiation spot (for high atmospheric pressure) or into the environment (for reduced pressures). In particular, for atmospheric pressure, the ablation process results in the formation of a deep crater, containing microscale spikes, covered by re-deposited nanoparticles [13-16]. In this case, chemical transformations in ablated species are minimal, since the ablated material rapidly cools down while interacting with the environment [24,43].

We recently introduced a novel method for surface nanostructuring, which is characterized by radically different nanofabrication conditions [44-49]. The method may look paradoxical, since it disaccords with main principles of laser processing requiring the minimization of plasma-related effects as one of main conditions to achieve high quality of laser treatment. In contrast, in this method, plasma-associated effects are amplified by all possible means. Basically, we use infrared radiation from CO_2 laser, which is strongly absorbed by the plasma itself. When focused in air and any other gas having atmospheric pressure, infrared radiation is capable of efficiently igniting the gas breakdown and this phenomenon is called the "laser spark". The presence of a target decreases the breakdown threshold by 2–3 orders of magnitude [50]. In the latter case, the target serves to provide first electrons. Then, an avalanche plasma discharge develops in ambient air moving towards the focusing lens. Absorbing main radiation power through the inverse Bremsstrahlung mechanism, the plasma accumulates an enormous amount of energy and is supposed to radically change conditions of nanocluster production and growth [51]. Indeed, in contrast to conventional laser ablation, the ablated species find themselves in a plasma "reactor" with extremely high temperatures (10^4 K) [52] and strong electromagnetic fields [53-56], yielding to a deep chemical transformation of properties of ablated clusters. The clusters then move back to the irradiated spot forming a film of clearly separated and densely packed spherical nanoparticles, as shown in Fig. 3a. The size of nanoparticles can vary for different materials, but is usually between 20 and 70 nm. The increase of plasma intensity can also lead to a coagulation of nanoparticles and the formation of much larger microscale spherical features. Nanostructures treated by this method have a specific