Application of Laser in Food Technology: An Overview

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Received: 20 March 2010 *Revised: 30 May 2010* *Accepted: 6 June 2010*

ABSTRACT

Lasers are now used in different areas of science and technology. They are used in food processing in particle size distribution, modifying packaging materials, disinfection, fiber optics and in machine vision system. The unique properties of laser radiation facilitate producing instruments with a high degree of accuracy and precision could be used successfully in different food quality control systems. Matrix assisted laser desorption ionization mass spectrum (MALDI-TOF-MS) has implemented in a lot of applications, in the assay of bioactive molecules, identification of bacterial cell proteins, and in the analysis of difficult proteins and verification of the gene sequence. Raman spectroscopy technique is also considered as an important laser tool for studying meat and meat products, protein isolates and plant pigments as well as, its role in detecting the adulteration is already being well known. Laser induced fluorescence methods (LIF) are now applied successfully as a system for a quality control in palm oil industry. Also, it can be coupled with other techniques like capillary gel electrophoresis (CG-LIF) detectors for the detection of genetically modified foods and flavin contents in different food products.

Laser is newly introduced in different modern microscopic techniques like confocal laser scanning microscopy (CLSM) and atomic force microscopy (AFM).

Keywords: lasers- laser in food processing- matrix assisted laser desorption ionization mass spectrum (MALDI-TOF-MS)- Laser induced fluorescence (LIF) –confocal laser scanning microscopy (CLSM)- atomic force microscopy (AFM).

INTRODUCTION

Laser is an acroname for light (**L**), amplification (**A**) by stimulated (**S**) emission (**E**) of radiation (**R**). Laser instruments generate an intense, stable and spectrally pure light beam, which may be focused down to spot of the order of micrometers in diameter (Melles 2009).

Lasers are devices that produce intense beam of light which are monochromatic, coherent and highly collimated. The wavelength of laser light is extremely pure (monochromatic) when compared to other source of light. All the photons (energy) that make up the laser beam have a fixed phase relationship (coherence) with respect to one another. Light from a laser typically has very low divergence. It can travel over great distances or can be focused to a very small spots with a brightness which exceeds that of the sun. Because of these properties, lasers are used in wide variety of applications in all the living sciences (Melles 2009).

The term "light" is generally accepted to be electromagnetic radiation from 1nm to 1800 nm in wavelength. Current instrumentation improvements involve the use of laser as a light source in place of more traditional lamps. The light power, directionality, colour purity and temporal coherence of the laser light make it an ideal source for inducing fluorescence. The application of laser induced fluorescence (LIF) technique in the field of food technology is already taken place and proved their accuracy. Indeed, the implementation of laser in both the processing and quality control of foods undoubtedly will lead to achieve a final product with a good manufacturing practice (Day, 1995).

Laser Instruments Used in Food Analysis:

a- Matrix assisted laser desorption ionization mass spectrum (MALDI-TOF-MS)

In this technique, accurate molecular weight information can be determined in minutes using small quantities of complete cells or fractions of further purification. The matrix (low molecular weight organic acid) is mixed with the sample and inserted on the target plate, then hit with the laser to be converted into ions using a voltage of

20 kv. The resulted ions are sterad into the (mass charge) usually plotted against ion abundance. The low molecular weight ions are accelerated to high speed and high molecular weight ions to low speed, and time dependence is detected. Time dependence detection is converted into accurate masses using previous calibration (Bromhead & Francis 2004). This soft ionization technique, enabled the MALDI to have a lot of applications in the field of food chemistry. (Fig. 1) shows the ionization pattern of MALDI.

b- Raman spectroscopy

The Raman effect occurs when light impinges upon a molecule and interacts with the electron cloud and the bonds of the molecule. For the spontaneous Raman effect, a photon excites the molecule from the ground state to a virtual energy state. When the molecule relaxes it emits a photon and it returns to a different rational or vibrational state. The difference in energy between the original state and this new state leads to a shift in the emitted photon's frequency away from the excitation wavelength (Chan, 1996).

In the final vibrational state of the molecule, it is more energetic than the initial state, then the emitted photon will be shifted to a lower frequency is designated as a Stokes shift. If the final vibrational state is less energetic than the initial state, then the emitted photon will be shifted to a higher frequency, and this is designated as an Anti-Stokes shift. Raman scattering is an example of inelastic scattering because of the energy transfer between the photons and the molecules during their interaction (Ghosh & Jayas, 2009).

A change in the molecular polarization potential or amount of deformation of the electron cloud with respect to the vibrational coordinate is required for a molecule to exhibit a Raman effect. The amount of the polarizability change will determine the Raman scattering intensity. The pattern of shifted frequencies is determined by the rotational and vibrational states of the sample (Langers & Lipp, 2000).

c- Confocal laser scanning microscopy (CLSM)

In a confocal laser scanning microscopy (CLSM), a laser beam passes through a light source aperture and then is focused by an objective lens into a small (ideally diffraction limited) focal volume within or on the surface of a specimen, in biological applications especially, the specimen may be fluorescent. Scattered and reflected laser light as well as fluorescent light from the illuminated spot is then recollected by the objective lens. A beam splitter separates off some portion of the light into the detection apparatus, which in fluorescence confocal microscopy will also have a filter that selectively passes the fluorescent wavelengths while blocking the original excitation wavelength. After passing a pinhole, the light intensity is detected by

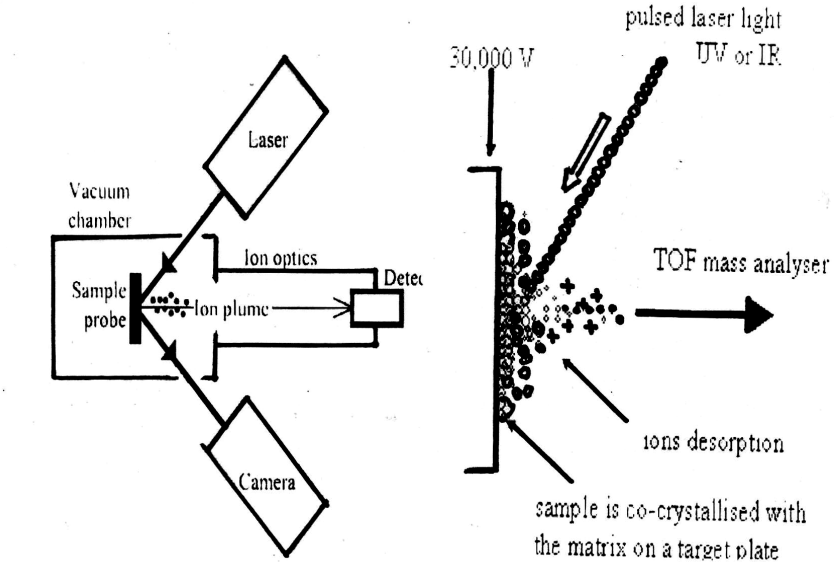

Fig. 1: The ion desorption plume moving from the matrix to the electric field accelerator (Bromhead & Francis 2004)

a photo detection device (usually a photomultiplier tube (PMT) or avalanche photodiode), transforming the light signal into an electrical one that is recorded by the computer (Renzetti *et al*. 2008).

A further advantages of CLSM is the possibility to follow the dynamics of processes such as phase separation, coalescence, aggregation, coagulation, solubilization…etc. Specially designed stages, which allow heating, cooling or mixing of the sample, give the possibility to simulate food processing under the microscope. Fig (2) shows the configuration of CLSM and their operating principles (Durrenburger *et al*. 2001).

Confocal laser scanning microscopy, has found numerous applications in different food science aspects (Renzetti *et al*. 2010), examples are as follows:

1– In cereal chemistry and technology.

2– In meat science and technology.

3– In the analysis of shear-sensitive.

4– In biopolymer mixtures.

5– In identification of microorganisms.

d– Atomic force microscopy (AFM)

Atomic force microscopy (AFM) is one of the newest tools based on laser. The AFM has been applied to investigate fine food molecular structure and molecular manipulating (Yang *et al*. 2007). In the atomic force microscopy, the normal force is measured by the bending of the micro-fabricated cantilever. This is detected by either an optical lever and split photodiode or less commonly, by an interferometric arrangement (Fig. 3). The AFM has been successfully used for study of pectin extraction, membrane formation of zein and catalysis of starch modification (Anderson & Guraya 2006).

e– Laser differaction particle size analyzer

Laser diffraction particle size analyzer as seen in (Fig. 4) provides indirect size measurements of spherically equivalent particles, based on the principle that particles of a given size diffract light through a given angle that increases logarithmically with decreasing size. Few grams of material are dispersed into a liquid that circulates across a quartz measurements cell illumenated by a laser beam. Different instruments have differently designed systems for stering the disspersent liquid

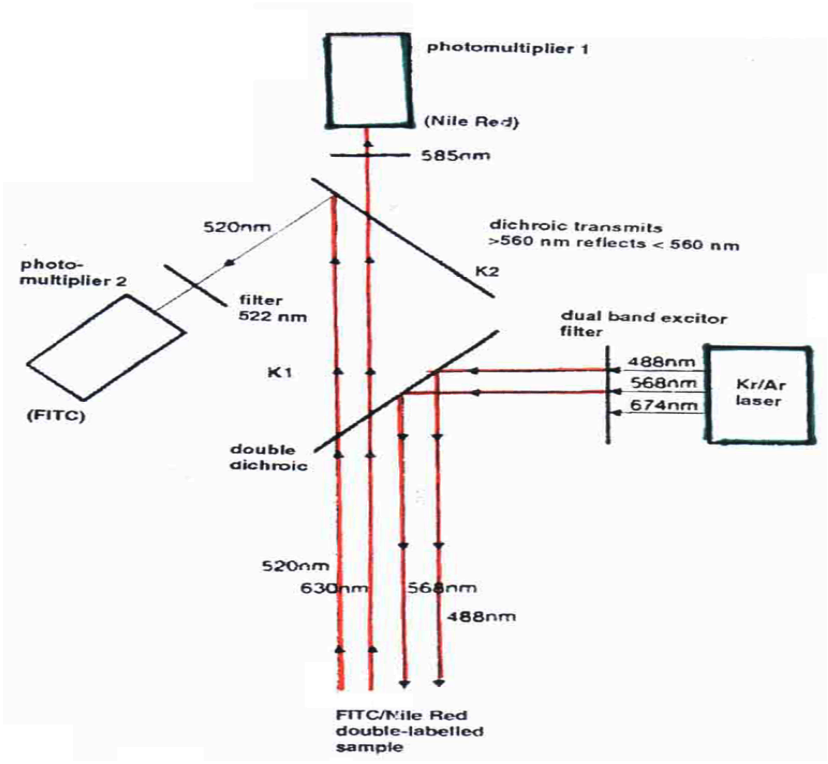

Fig. 2 optical ray diagram for the simultaneous detection of FITC and Nile Red using the orange-krypton mixed-gas laser (adapted from the BioRed MRC600operating manual) (Renzetti *et al*. 2008).

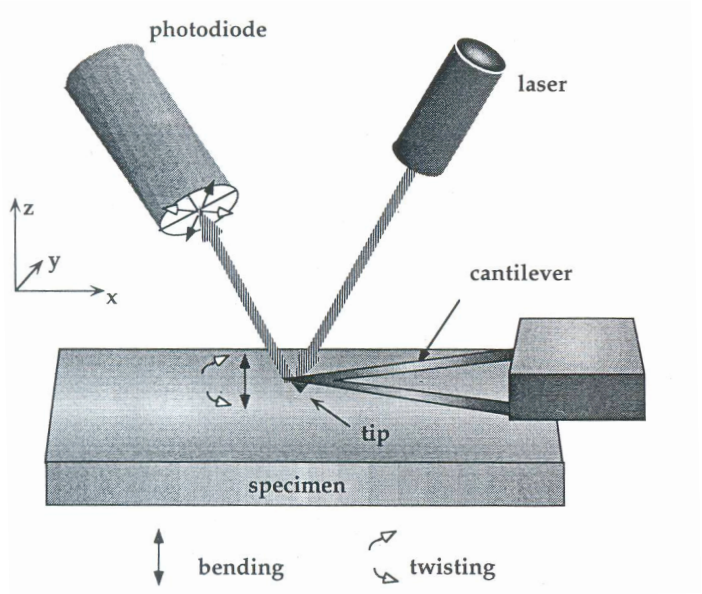

Fig. 3: The basic AFM arrangement presented in schematic form. In this illustration, force detection is via a quadrant detector so that both normal and lateral force measurements can be made (Yang *et al.* 2007)

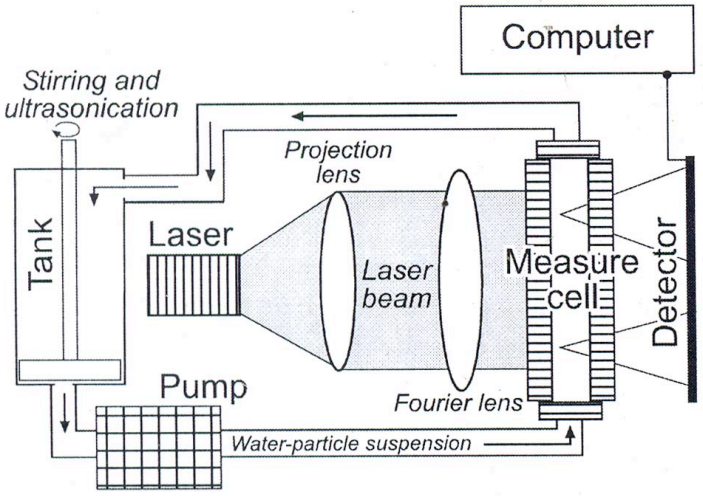

Fig. 4: Main components of a laser diffraction particle size analyzer (Stori & Balsamo 2010)

into the tant and ensuring its circulation through the measurement cell by mechanical means. A wide variety of standard operating procedure can be set up in laser diffraction particle size analyzer. They include the pump speed, the number of measurement runs, the length of the measurement knive and the use of dispersing agents and/or ulltasonication to aid sample disagregation and dispersions. (Storri & Balsmo 2010).

Applications of laser in food technology

Numerous applications of laser have been applied and part of it, is already implemented successfully in food during processing. The CO_2 lasers have been used experimentally for cutting a wide variety of foods. Also microwave amplification by stimulated emission of radiation (MASER) has found suitable application for the quick heating of juice concentrates, inactivation of enzymes and peeling of foods (Day, 1995). These applications could be classified into the following main items.

A– Disinfection and sanitary control

One of the techniques that have a wide application now is the laser optical flow cytometetric techniques (Pinder & Codfrey, 1994). Recently, this

technique has found a wide application in food technology through the use of specific-immunochemical labels such as monoclonal antibodies, which insure this novel approach to provide new solution for an even wider range of industrial user.

Lasers are now applied in changing the surface structures of packaging materials to be suitable for fresh produce application, for scoring of packaging materials, for easy opening of food pouches, roll wrappers, sealed trays and aseptic control (Ozdmir *et al*. 1999). Carton sterilization by UV. Excimer laser (248 nm) proved its efficiency, since the germination ability of Bacillus spores is alterated (Wariner *et al*. 2002), as an alternative to the use of chemicals for cleaning and disinfecting surfaces of equipments; pulsed laser beams could be implemented successfully for the removal and killing of adherent bacteria without visible alteration of the surface (Sadoudi *et al*. 1997).

B- Food proteins:

a. Meat quality evaluation

The UV laser desorption technique offered accurate measurements of large proteins like porcine pepsin (MW 32.700), porcine trypsin (MW 23.800) and -galactosidases (MW 116.000) (Spengler & Cotter 1990).

Regarding the protein chemistry, matrix assisted laser desorption ionization (MALDI) can be combined with enzymatic treatment to provide structural information of three level molecular masses, primary maps and primary structures of proteins (Fenselau 1997). Moreover, the measurements of large fragile biopolymers over 35.000 Da can be estimated accurately. Also, the classification and changes that occurred in potato proteins (Pots *et al*. 1999) and fate of nisin (Rose *et al*. 1999) could be rapidly detected.

Recently, new methods for the rapid and non-destructive evaluation of meat quality in an intact carcass have been developed to speed up the grading of fresh meat. Fiber optics can simply do that, through measuring the refractive index (RI). Bulk refractive index is measured with an Abbe reflectometer using a red laser for transmittance and the green laser for reflectance; thereby RI can be detected photometrically (Swatland 2002).

Raman spectroscopy of cooked beef has also a considerable protential as a method for non-destructive and rapid determination of the beef quality parameters. Raman measures the -helix and sheet ratio of the myofibril proteins which are considered to be the important factors, that contributing to shear force, tenderness, texture and overall acceptability of the beef (Beattie *et al*. 2004).

b- Plant proteins evaluation

Raman spectroscopy, could be also used to measure the level of modifications in food proteins; this can be done as long as changes in new or existing Raman bands can be quantitatively measured. For example the band intensity at 1737 cm^{-1} could be taken as a measuring index of C=O band in $RCOO^-$ groups (Zahoo *et al*. 2004).

Size exclusion chromatography- multiangle laser light scattering (SEC-MALLS) can also be used to monitor thermal aggregation of plant seed storage protein with limited solubility. When the dynamic light being scattered, the dimensions of various oligometric forms of oat globulin can be estimated (Zhao *et al*. 2004).

c- Cereal quality

Devaux *et al*. (1998) investigated the relevance of measuring particle size distribution by laser-diffraction in order to compare flour fractions collected along a milling diagram. The advantages of laser diffraction was that it was possible to precisely describe particle size <50 μm. The main differences between hard and soft wheat flour was in the proportion of isolated starch granules freed when the grains were fragmented. The 25 μm mode could be considered as a representative of the ability of the wheat to free starch granules and could be used to follow a grinding or milling process. Overall, a laser diffraction particle sizing method using non-polar dispersant provides a suitable particle sizing technique for infant formula products that is superior to the air dispersion method (Kwak *et al*. 2009).

In the field of cereal chemistry, the MALDI can be used to verify the sequence of a substantial part of single high molecular weight of glutenin subunits. Analysis using reverse phase HPLC treated with triptic enzyme allowed 80% of the sequence to be confirmed (Foli *et al*. 2000).

The FT- Raman spectroscopy is now applied in the field of cereal chemistry to characterize chemically modified starches, to study oat globulin conformation and to on-line monitoring applications for industrial quality control during the starch chemical modification (Ma & Phillips 2002).

d- Genetically modified foods

By the use of laser induced fluorescence detectors, (488 nm argon ion laser), the detection of genetically modified foods (GMF) are becoming feasible. The speed and sensitivity of capillary gel electrophoresis – laser induced fluorescence (CE-LIF) opened the way for various applications in molecular biology and in the identification of transgenic foods (Atulia 1996). Use of LIF with derivatising reagents (phaladelyde- fluorescein isothiocynate FIT) has been proposed as an alternative to exhibitly fluorescence depending on the mechanisms of intercalating.

By using the PCR-CGE-LIF procedure, samples containing transgenic maize at concentrations 1, 0.5 and 0.01% could be easily detected (Canas *et al*. 2002).

4- Other Foods

The soft ionization technique enabled the MALDI to have a lot of applications in the field of food chemistry. It is considered to have a valuable tool for the analysis of anthocyanins in food samples (Wang *et al*. 1999) and can provide the results within few seconds. Also MALDI could be applied in the analysis of bioactive molecules like polyflavones and barley β-glucans (Tang *et al*. 1993).

Laser can be applied now in the quality control of crude oil industry. The excitation source was a 632.nm He-Ne laser with an output power of 5mw. The laser beam enters a quartz cell at 90° to the incident laser beam. The fibre optic then focuses the fluorescence into 250 µm entrance slit of a monochromator. The fluorescence signal is then amplified as it passes through the optical multichannel analyzer (OMA). The OMA output is subsequently fed to microcomputer via a detector interphase and the fluorescence spectrum and intensity are displayed on the monitor (Tan *et al*. 1995).

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تطبيقات الليزر في تكنولوجيا الأغذية: نظرة شاملة

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تستخدم أشعة الليزر في العديد من مجالات العلم والتكنولوجيا وتستخدم حالياً في العديد من مجالات الأغذية المختلفة حيث تستخدم في تتبع توزيع الجزيئات وتعديل مواد التعبئة والتغليف ومجالات التعقيم وتكنولوجيا الألياف الضوئية.

وقد مكنت الصفات الفريدة لليزر من إنتاج أجهزة ذات درجة جودة ودقة عالية مما أدى إلى استخدامها بنجاح فى العديد من طرق التحكم في الجودة في مصانع الأغذية. وقد ساعد ابتكار مطياف الكتلة الذى يعمل بالليزر Matrix Assisted Laser Desorption Ionization Mass Spectrum (MALDS-TOF-MS) على الاستفادة به في العديد من التطبيقات مثل التعرف على الجزيئات ذات الفعالية الحيوية، التعرف على بروتينات الخلايا الميكروبية، تحليل أنواع البروتينات ذات التركيب البنائى الصعب والتعرف على التركيب الجينى فى المادة الغذائية.

وقد استخدمت تكنولوجيا Raman والتي يستخدم فيها الليزر فى العديد من التطبيقات كدراسة اللحوم ومنتجاتها، مركزات البروتينات، الأنواع المختلفة من الصبغات الطبيعية الموجودة في النباتات، ومن ناحية أخرى فهناك بعض الطرق التى تعتمد على الوميض الناتج عن الليزر Laser Induced Fluorescence (LIF) والتى تم تطبيقها بنجاح كنظام للجودة فى التعرف على زيت النخيل أو دمجها فى بعض الطرق مثل طرق الهجرة الكهربية للتعرف على الأغذية المهندسة وراثياً.

تجدر الإشارة إلى أن الليزر يستخدم حديثاً في العديد من الطرق الميكروسكوبية لإنتاج العديد من الميكروسكوبات التى تعمل بأشعة الليزر مثل Confocal Scanning Laser Microscope (CSLM) و Atomic Force Microscope (AFM).