Fabrication of nanofiber reinforced polymer microstructures through two photon polymerization

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Femtosecond laser micromachining has become increasingly important in recent years for many fields, including micro-optics, micro-electronics, micro-biology, and micro-chemistry. Laser ablation, because of its non-contact nature, allows the micromachining and surface patterning of materials with minimal mechanical and thermal deformation. It is now well known that for many of these applications, the femtosecond regime offers advantages over the nanosecond regime. These advantages lie in its ability to deposit energy into a material in a very short time period, before thermal diffusion can occur. As a result, the heat-affected zone, where melting and solidification can occur, is significantly reduced. Smaller feature sizes, greater spatial resolution, and better aspect ratios can hence be achieved.

Another advantage of femtosecond laser micromachining is its versatility in terms of both the materials that can be processed and the type of processing. A variety of materials have been demonstrated to be suitable for femtosecond laser micromachining, such as metals, semiconductors, polymers, oxide ceramics, silica aerogels, optical glasses, and crystals. Avariety of processing methods have been used, including the fabrication of photonic crystals, waveguides, gratings and single mode couplers, and the storage of data.

Two-photon polymerization (2PP) is a direct laser writing technique, which allows the fabrication of 2D and 3D structures with a resolution (structure size) down to 100nm [4, 5]. This microstructuring technique is based on the interaction of femtosecond laser radiation with a photosensitive material which induces a highly localized chemical reaction leading to polymerization of the photosensitive material. 2PP allows the fabrication of computer-generated 2D and 3D structures by direct laser ‘‘recording’’ into the volume of a photosensitive material. Due to the threshold behavior and nonlinear nature of the 2PP process, resolution beyond the diffraction limit can be realized by controlling the laser pulse energy and the number of applied pulses.

Polymer is an important material for constructing biomedical microelectromechnical systems (MEMS). Its flexure provides more comfort to patient than conventional silicon based MEMS [6]. More importantly, polymers are biocompatible. However, microdevices made of polymers have lower mechanical strength and modulus compared to metals. By filling the polymer matrix with another material, normally fillers such as particles, tubes and fibers, the mechanical strength of polymer can be improved. When the size of filler reduces to nanoscale, surface area of polymer/filler interface can be much larger than that created with conventional fillers [8, 9]. Therefore, significant improvement in mechanical strength is possible with nanofiller-enhanced composite. Moreover, nanofibers have very special properties compared to bulk materials or even micron-sized particles. These special properties encompass thermodynamic, chemical, mechanical and optical behavior.

In this work, we describe a new fabrication method via two photon polymerization of resin dispersed with nanofibers. This research proposal presents a new method for the formation of microfeatures with reinforced polymer using femtosecond laser material processing. The femtosecond laser was used for the generation of three-dimensional interweaved nanofiber and the construction of microfeatures, like microchannels and voxels, through two photon polymerization of nanofiber dispersed polymer resin. This new method has the potential of direct fabrication of reinforced micro/nano structures. The mechanical properties and of nanofiber reinforced polymer microstructures were investigated by means of nanoindentation.

The electrical conductivity of the nanocomposite formed by the incorporation of the generated nanofibers in a polymer matrix is investigated. The conductivity of the microstructure was measured by a two-probe system at room temperature and the conductivity-temperature relationship was measured between 20-140 oC. The effect of the repetition rate of the femtosecond laser on the electrical conductivity of the reinforced polymer was also studied. Results showed that the electrical conductivity of the reinforced polymer increases with the increase in the repetition rate of the femtosecond laser. Finally, the concept of electrical sensitivity was introduced to show how sensitive and to what extent the reinforced polymer resistance responds after being stimulated by the temperature change.

Even though extensive work has been done on the fabrication of polymeric two or three dimensional structures, to the best of our knowledge, no work has been done on the direct writing of nanofiber reinforced polymeric structures.