

Terahertz transmission properties of Cr ion implantation glass

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Cr ion implantations in glass with the different doses of $D=1.493\times 10^{17}$ and 4.976×10^{17} ion/cm² are obtained by metal vapor vacuum arc (MEVVA). The effects of the different Cr ion implanted doses on terahertz (THz) transmission property are analyzed from THz time-domain spectroscopy. The results show that the more the Cr ion implanted dose in the micro-area implantation glasses, the larger the THz transmission except the larger absorption at 0.24 THz. This is an effect attributed to the coupling of plasmas on both the implantation and the implantation affected zones of the Cr ion implantation glass.

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The unique optical properties of metal are at the core of many areas of the research and applications, such as plasmonics^[1–5], metamaterials^[6,7], superlensing^[8,9], terahertz (THz) enhancement^[10,11], and so on. Presently, metal ion implantation into non-semiconductor material, which nitrogen ion implantation cannot realize, is a currently developed and potential enhancement material surface processing technology. It makes the research on surface properties and the applications more comprehensive and dramatic. Material modification is produced by metal vapor vacuum arc (MEVVA) source implantation at high target temperature with high ion flux. The effective parameters on the optical properties of the modified surfaces are ion species, energy, dose, and ion flux. Cr ion implantation technology has many applications in decoration such as jewellery coloring, improving corrosion resistance, and hardening surfaces, and so on^[12,13]. The implantation of transition metal ions in glasses can lead to the formation of nanometer-sized colloidal particles embedded in a thin surface layer, which will affect the optical transmission property.

Compared with the generally used infrared spectroscopy, Raman spectra, and X-ray diffraction methods for analyzing the surface properties, THz time-domain spectroscopy (TDS) is a new technique that uses pulsed THz radiation to characterize the optical properties of many kinds of materials, such as nanophase material and thin dielectric films^[14–17]. With THz TDS system, not only can the average time-dependent information be measured but also the complete frequency-dependent information can be obtained. Characterizing materials in the range from gigahertz (GHz) to THz is critical for the development of new technologies in integrated circuitry, photonic systems, and micro-electro-mechanical systems. In this letter, THz TDS system is introduced to analyze the effect of the Cr ion implanted dose on optical properties of the ion implantation glass in the THz range, which is helpful to obtain the material with THz

enhanced transmission mechanism. Cr ion implantations are modified by MEVVA with the pulsed voltage of 30 kV and doses of $D_1=1.493\times 10^{17}$ and $D_2=4.976\times 10^{17}$ ion/cm². The thickness of all the glass is 1.06 mm. The color of the implantation glass becomes darker from gray to black with the increase of the Cr ion implantation dose.

The experimental setup of THz TDS system is shown in Fig. 1. A Ti:sapphire ultrashort pulse laser with central wavelength of 800 nm, pulse width of 200 fs, and repetition rate of 76 MHz is used as a pump laser. The femtosecond laser is split by beam splitter P1 into two beams: pump beam (strong beam) and probe beam (weak beam). The pump beam illuminates on the THz emitter. The generated THz wave is focused on the center of the sample by parabolic reflector M7. The mechanic delay line is to change the time delay between THz pulse and the probe pulse, and the THz electric field waveform can be obtained by scanning time delay. To increase the sensitivity, the pump beam is modulated by a mechanical chopper, and the THz induced modulation

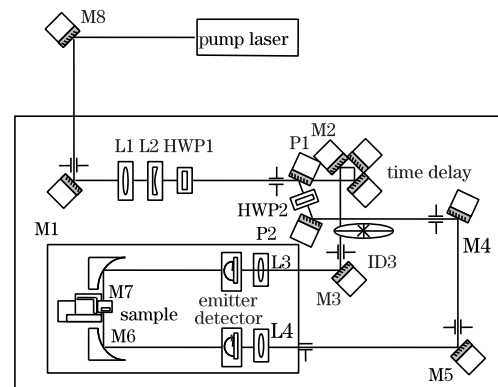


Fig. 1. Experimental setup of THz TDS system. M: mirror; P: polarizer; L: lens; HWP: half-wave plate.

on the probe beam is extracted by a lock-in amplifier. Using THz TDS, one can obtain a rapid spectral measurement over a very large bandwidth in the THz range.

In order to clearly understand the optical property of the Cr ion implantation glass, the THz waveforms of the Cr ion implantation glass with the different implantation doses of D_1 and D_2 , and a pure slide glass in time domain are shown in Fig. 2. One can see that the THz absorption in the Cr ion implantation glass is larger than the absorption in the slide glass. The more the Cr ion implantation dose is, the larger the enhancement of the THz pulse is, which indicates the coupling of the plasmas in the implantation and implantation affected zones (Fig. 3). The first zone is implantation one, where the doping ions stay and combine with the atoms of the bulk material to form this implantation zone. And its thickness is 50–200 nm, which improves surface property of the material. The implantation affected zone of 100- μm thickness is induced by ion bombard mechanics effect under the implantation zone, where there are many nodes and line dislocations. Moreover, the THz time delay in the Cr ion implantation glass is shorter than that in the slide glass. Owing to the Cr ion implantation, the refractive index in the implantation zone of the glass is larger than that in the slide glass, while the refractive index in the implantation affected zone is smaller than that in the slide glass. And the affected area is larger than the implantation one.

By Fourier transform, Fig. 4 shows their corresponding THz transmission spectra normalized by the result in the atmosphere. One can see that the more the Cr ion implantation dose is, the higher the THz transmission goes. And the THz transmission spectra in Cr ion implantation glasses are different from that in the slide glass. The transmissivities in the glasses with implantation doses of D_1 and D_2 reach the maxima of 0.23 and 0.55 at 1.31 and 1.17 THz, respectively, while the

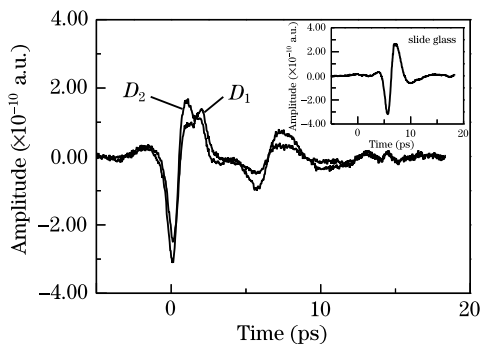


Fig. 2. THz waveforms of the Cr ion implantation glass with the different implantation doses of D_1 and D_2 , and a pure slide glass in time domain.

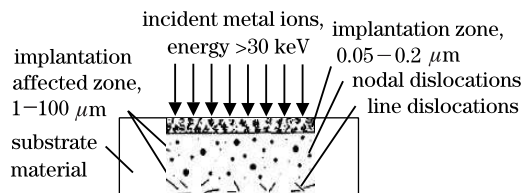


Fig. 3. Doping diagram of metal ion micro-area implantation with high ion flux.

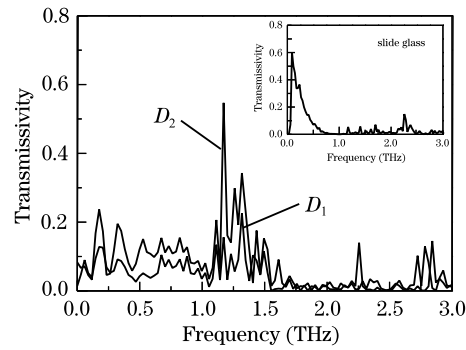


Fig. 4. THz transmission spectra corresponding to the three kinds of glasses.

transmissivity in the slide glass is zero at the same frequency. And there is two maximal transmissivities of 0.6 and 0.37 at 0.08 and 0.23 THz, respectively, in the slide glass, however the transmissivity in the Cr implantation glass is suppressed to about 0.05. It is obtained that there is an absorption peak at about 0.24 THz in these micro-area implantation glasses. Based on the dielectric parameters of Cr for the Lorentz-Drude model^[18], there exists the oscillation effect at 0.24 THz, and electric conductivity of Cr $\sigma = 3.8 \times 10^7$ s/m, the skin depth at 0.24 THz is 158 nm, nearly equals the thickness of the Cr ion implantation area, which can reduce the transmissivity at 0.24 THz. The implantation of transition Cr ions in glasses can lead to the formation of nanometer-sized colloidal particles embedded in a thin surface layer, which forms a waveguide structure. The surface plasma wave is excited when the light passes through this area. Except at 0.08 and 0.23 THz, the THz transmission enhancement may be explained by the surface plasma excitation and the lightning rod effect based on the localized field enhanced model^[19].

In conclusion, the optical property of the slide glass with the different Cr ion implanted doses is analyzed by using THz TDS. Compared with the pure slide glass, the Cr ion implantation glass has shorter time delay and different transmission spectra. The more the Cr ion implantation dose is, the higher the THz transmission goes, except the larger absorption at 0.24 THz in the micro-area implantation glasses. This is an effect attributed to the coupling of plasmas on both the implantation and the implantation affected zones of the Cr ion implantation glass.

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