# Study on terahertz response of FC-40 based on microfluidic technology

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**Abstract:** FC-40 is a colorless and tasteless fluorine oil, which has important application value in the fields of medical equipment and biological detection. In this study, the terahertz technology was combined with microfluidic technology to study the terahertz transmission characteristics of FC-40 after standing under electric and magnetic fields for different time, respectively. It is found that the transmission intensity of terahertz spectra of FC-40 increases with the increase of standing time in external electric field and magnetic field. The microscopic change is deduced from the change of transmission intensity of liquid, and the influence of electric field and magnetic field on polar covalent bond of C-F is analyzed in detail. The results show that the transmission intensity of FC-40 increases with the increase of standing time in electric and magnetic fields. This study provides technical support for improving the detection sensitivity of biomolecule in fluorine oil.

## 1. Introduction

Terahertz (THz) radiation refers to electromagnetic waves with a frequency in the range of 0.1-10 THz, and a wavelength of 3000-30 μm, which is between microwave and infrared in the electromagnetic spectrum[1-3]. At present, many studies have shown that the characteristic energy of rotation and vibration of most biomolecules is in the THz range[4-7], which provides a theoretical basis for the identification of biomolecules using THz waves.

FC-40 is a perfluorinated oil, whose name is perfluorotributylamine, and its molecular formula is $(C_4F_9)_3N$. It has the advantages of high thermal stability, high oxidation stability, good chemical inertness, strong corrosion resistance, good lubricating performance and high decomposition temperature. Therefore, FC-40 is widely used in the fields of electronics, oil and gas, environmental monitoring, military affairs, chemical cleaning, medicine, nuclear industry, etc. Considering its stability, FC-40 can also be used as lubricant, hydraulic oil and heat carrier. In the study of biomolecules, the biological environment is generally liquid water which can easily absorb THz waves. At the same time, FC-40 has high permeability to THz waves. Yang et al. used FC-40 as an optical cleaner, whose function is to replace water molecules around living cells, so that the THz response of living cells in FC-40 can be clearly observed under THz spectrum. They also quantified the cell viability under drug treatment by THz spectrum, which provides a convenient and efficient cell analysis method for the detection of living cells and their activity analysis by THz spectrum[8].

To investigate the optical properties of FC-40, we have introduced microfluidic technology to manipulate and analyze it. Microfluidic technology is a kind of science and technology which can accurately control micro scale fluid. At present, microfluidic technology has been widely used in the fields of chemistry, physics and biological detection because of its advantages of less liquid sample consumption, fast detection speed and simple operation. Duponchel et al. designed a sub THz microfluidic chip[9]. The chip used silicon as substrate and quartz as cover, in which quartz has high THz transmittance. Finally two water shells of ethanol/water system in the frequency range of 10 ~ 90 GHz were observed by THz spectroscopy combined with microfluidic technology. Tang et al. proposed a microfluidic chip structure for cell capture, and used this chip to study the terahertz

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spectrum of living cells[10]. The above studies show that it is feasible to combine THz technology with microfluidic technology to study liquid samples.

In this study, a microfluidic chip was designed and fabricated, and the THz transmission characteristics of FC-40 were studied by THz-TDS system. It is found that the THz transmission intensity will increase slightly with the increase of the standing time of FC-40 in electric and magnetic fields and the strength of electric and magnetic fields. It provides a feasible method for improving the detection sensitivity of cells in fluorine oil. At the same time, the study of the relationship between the THz transmission intensity of FC-40 and the electric and magnetic fields will contribute to the in-depth study of FC-40 in the THz field and lay a foundation for the study of THz and biotechnology.

## 2. THz-TDS system and microfluidic chip

### 2.1 THz-TDS system

In this study, a self-built THz-TDS system was used. The light source was a self-mode-locked fiber femtosecond laser (Peking University, with a center wavelength of 1550 nm, a pulse width of 75 fs, a pulse repetition frequency of 100 MHz, and an output power of 130 mW). The output laser is divided into two beams after passing through the polarization splitting prism. One beam is used as the pump channel and coupled to the optical fiber photoconductive antenna (bapca-100-05-10-1550-c-f, batop company) through the mechanical translation platform to generate THz waves; the other beam of light is coupled to the optical fiber photoconductive antenna (bapca-180-05-10-1550-c-f, BATOP company) as the detection path to detect THz waves. The fabricated microfluidic chip is placed in the middle of the two antennas. After the THz waves pass through the microfluidic chip filled with liquid, they are received by the detection antenna and input to the lock-in amplifier for amplification. Then the computer is used for data acquisition and processing.

### 2.2 Microfluidic chip

In this study, the substrate and cover of the THz microfluidic chip are made of Zeonor 1420R. Its refractive index dispersion in the THz waves can be ignored, the absorption of the THz waves is weak, and its raw materials are cheap and easy to obtain[11]. Thus, Zeonor 1420R is the best material for fabricating microfluidic chips. In the microfluidic chip, the substrate and cover plate are bonded with double-sided adhesive with a thickness of 50 μm, and the middle of the double-sided adhesive is hollowed out for storing the solution to be tested, as shown in Figure 1.

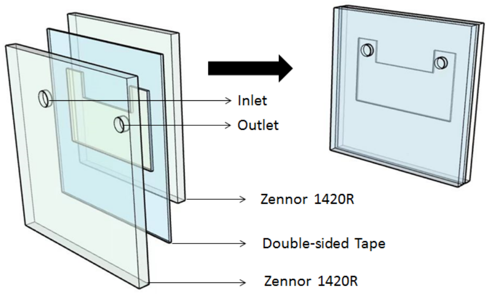


Figure. 1 Schematic diagram of microfluidic chip manufacturing process

### 2.3 External electric and magnetic field device

In this study, a set of devices which can be used to apply an electric field to the sample to be tested is designed, and its schematic diagram is shown in Figure 2. First, a plexiglass support was designed and fabricated to fix the microfluidic chip and the electrode plates, and the distance between the electrode plates was 4 cm. The high-voltage power supply module (DW-P153-05C51) provides voltage for the electrode plates, and its output voltage can be changed between 0 and 10000 V by adjusting the potentiometer.

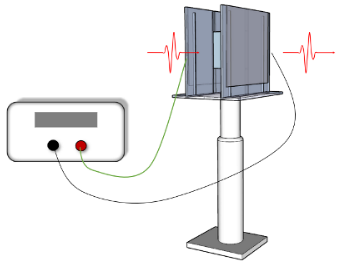

Figure. 2 Schematic diagram of applied electric field device

In addition, a set of device which can be used to apply a magnetic field to the sample to be tested is designed in this study, and its structure is shown in Figure 3. In this experiment, the magnetic field is provided by two electromagnets, which are powered by GPS-2303C regulated power supply. The magnetic field intensity generated by the electromagnet can be changed by adjusting the output voltage of the regulated power supply (output voltage range: 1–30 V). The working voltage used in this experiment is 20 V, and the magnetic field intensity is about 70 mT.

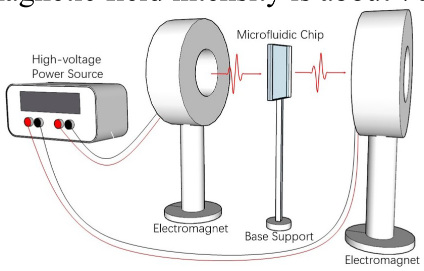


Figure. 3 Schematic diagram of external magnetic field device

## 3. Experiment

### 3.1 Influence of electric field intensity

First, fill the microfluidic chip with FC-40, then seal the liquid inlet and outlet with adhesive tape, fix the chip on the plexiglass support, finally, measure the THz transmission intensity of FC-40 under the electric field intensity of 0, 2500, 5000, 7500 and 10000V/cm. As shown in Figure 4 (a) and (b), the transmission intensity of FC-40 increased slightly with the increase of electric field intensity.

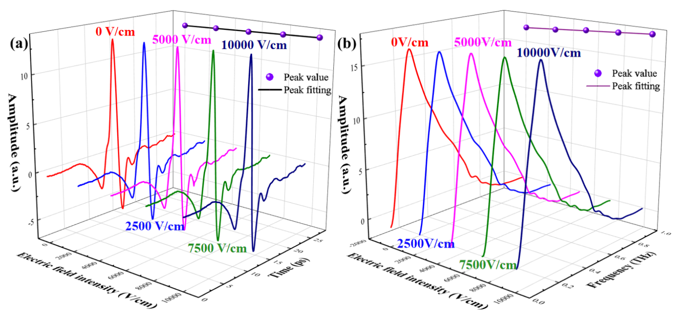


Figure. 4 THz spectra of FC-40 under different electric fields. (a) THz time domain spectra and (b) THz logarithmic frequency domain spectra

### 3.2 Influence of standing time in electric field

In order to make the experiment of studying the relationship between FC-40 standing time in electric field and THz transmission intensity more obvious, we hope to increase THz transmission intensity. According to the research result of the relationship between electric field intensity and THz transmission intensity, we finally chose to measure the effect of FC-40 standing time in the electric field when the electric field strength was 2500 V/cm. The THz time domain spectra and frequency-domain spectra of FC-40 are shown in Figure 5 (a) and (b). It can be found that as FC-40 remains in the electric field for a longer time, its THz time domain spectra and frequency domain spectra strength would be slightly enhanced.

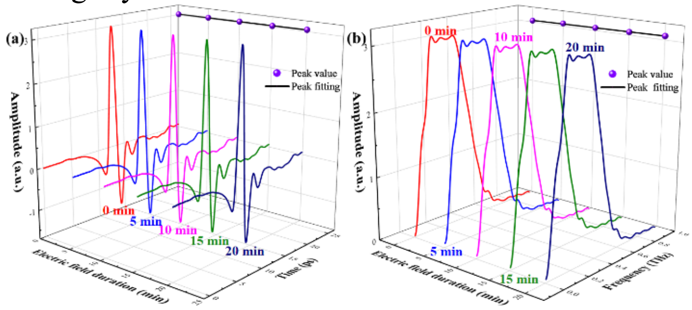

Figure. 5 THz spectra of FC-40 under electric field for different time (a) THz time domain spectra and (b) THz logarithmic frequency domain spectrum

### 3.3 Influence of magnetic field strength

When studying the influence of magnetic field on the transmission intensity of FC-40, the microfluidic chip filled with FC-40 was placed under the magnetic field of 5 mT, 10 mT, 15 mT and 20 mT for 5 min, kept the chip perpendicular to the THz wave propagation direction, finally the THz transmission intensity curves under different magnetic fields were obtained. The THz time domain spectra and frequency domain spectra of FC-40 are shown in Figure 6 (a) and (b). It is found that the THz transmission intensity of FC-40 increases slightly with the increase of magnetic field intensity.

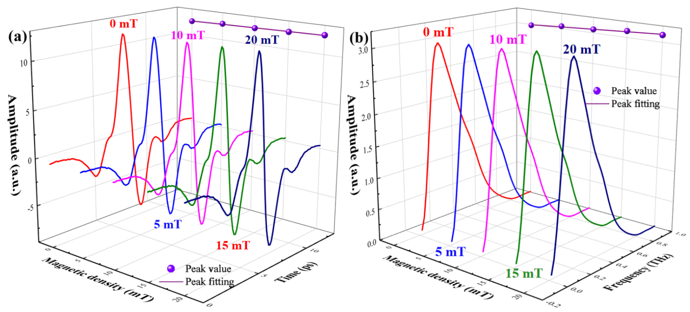

Figure. 6 THz spectra of FC-40 under different magnetic fields. (a) THz time domain spectra and (b) THz logarithmic frequency domain spectra

### 3.4 Influence of standing time in magnetic field

Similar to the experiment of studying the change of standing time of FC-40 under electric field, we take a larger magnetic field strength to enhance the experimental phenomenon. Therefore, we measured the influence of the standing time in the magnetic field on the THz transmission intensity of FC-40 under the magnetic field of 20 mT.

Similar to the previous experiment, the THz transmission intensity curve of FC-40 was obtained when it was placed in a magnetic field of 20 mT for 0, 5, 10, 15 and 20 minutes. The THz time-domain spectra and frequency-domain spectra of FC-40 are shown in Figure 7 (a) and (b). It can be found that as FC-40 remains in the magnetic field for a longer time, its THz time domain spectra and frequency domain spectra strength is slightly enhanced.

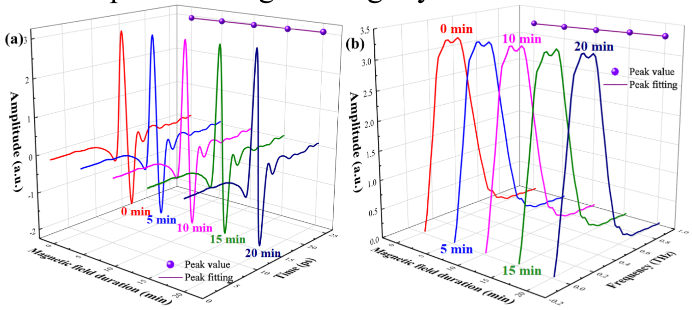

Figure. 7 THz spectra of FC-40 under magnitic field for different time (a) THz time domain spectra and (b) THz logarithmic frequency domain spectrum

## 4. Discussion

### 4.1 THz Spectral Characteristics of FC-40 in Electric Field

It is known that under the action of external electric field, the Hamiltonian of perfluorotributylamine molecular system can be expressed as：

$$\hat{H} = \hat{H}_0 + \hat{H}_{int} \tag{1}$$

Where $\hat{H}_0$ is the Hamiltonian when the external electric field is zero; $\hat{H}_{int}$ is the Hamiltonian of interaction between external electric field and molecular system. Under dipole approximation, the relationship between external electric field strength F and $\hat{H}_{int}$ is expressed as follows：

$$\hat{H}_{int} = -pF \tag{2}$$

Where $p$ is the molecular electric dipole moment and $F$ is the electric field strength.

The chemical bonds in perfluorotributylamine mainly include C-C bond, C-N bond and C-F bond. Among them, the physical and chemical properties of C-C bond and C-N bond are relatively stable, and their bond energy is almost unchanged under electric field[12]. In contrast, C-F bond is a polar covalent bond, which is unstable and greatly influenced by external incentive.

According to the formula (1) and (2), when the electric field strength F increases, the molecular electric dipole moment $\mu$ increases and the Hamiltonian $\hat{H}$ also increases. With the increase of applied electric field strength, the force of electric field on C-F bond increases. In order to balance the applied electric field, the molecular dipole moment increases, the total molecular energy decreases, and the stretching vibration and torsional vibration of C-F bond weaken, which leads to the weakening of absorption of THz wave by molecular vibration and the increase of THz transmission intensity. At the same time, with the increase of standing time in electric field, the number of stretched C-F bonds in the solution gradually increased, the absorption of THz by C-F bonds gradually weakened, and the transmission intensity increased.

### 4.2 THz Spectral Characteristics of FC-40 in Magnetic Field

When a magnetic field is applied, due to the effect of the magnetic field, the intermolecular force in FC-40 decreases, the distance between molecules increases, and the local density around a single molecule decreases, making it easier for THz waves to pass through. According to the experimental results, this change will increase the transmission intensity within 0.1-0.6 THz. When the strength of the magnetic field becomes larger or the standing time becomes longer, the effect of the magnetic field on the molecules in the solution gradually accumulates, and the phenomenon gradually increases. As a result, with the increase of the magnetic field strength and the standing time, the THz transmission intensity gradually increases.

## 5. Conclusion

In this study, the effects of the intensity of electric field and magnetic field and the standing time in electric field and magnetic field on the THz transmission intensity of FC-40 were studied by using microfluidic chip. It was found that the THz transmission intensity of FC-40 increased in all four experimental results. This is because the electric field will reduce the energy of the perfluoro-tributyl amine molecule and weaken the tensile and torsional vibration, thus weakening the absorption of the perfluoro-tributyl amine molecule to THz wave. Magnetic field will cause resonance in FC-40 molecules and change the molecular configuration. And the increase of electric field and magnetic field on the scale of field strength and placement time will lead to the increase of THz transmission intensity of FC-40. The results show that the transmission intensity of FC-40 increases with the increase of standing time in electric and magnetic fields. This study provides technical support for improving the detection sensitivity of biomolecule in fluorine oil.

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