Research progress on infrared stealth fabric

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Abstract: According to the detection method of infrared detection system and Stefan-Boltzmann’s law, the working principle of infrared stealth is analyzed. Some methods for achieving infrared stealth effect are summarized: reducing the infrared emissivity of fabric surface and controlling the surface temperature of fabric. The research included four kinds of infrared stealth materials such as low emissivity coating materials, temperature control coating materials, intelligent stealth clothing materials and bio-bionic stealth materials. The problems existing in the research of infrared stealth fabrics are pointed out. On this basis, the future development direction of infrared stealth materials is prospected.

1 Introduction
Infrared is one kind of electromagnetic wave with the wavelength of 0.76~1000 μm. The infrared radiation of the objects will be attenuated because of physical processes such as absorption, scattering and refraction. Only infrared rays of specific wave band can propagate through the atmosphere. Atmospheric attenuation bands for infrared include: 0.76~2.60μm band, 3~5μm band, 8~14μm band, which are called atmospheric infrared windows. Moreover, these three band was used in infrared thermal imaging system for the infrared protection. Today, infrared detection technology continues to develop and the stealth effect of infrared stealth fabrics plays a greater role in military use.

2 Basic theory of infrared stealth fabric
According to Stephen-Boltzmann law: [¹]

\[ E = \sigma \varepsilon T^4 \]

Where E is the infrared radiation of the object; \( \sigma \) is the Stephen-Boltzmann constant; \( \varepsilon \) is the emissivity of the object; T is the absolute temperature of the object.

It can be seen that E depends on the temperature T and emissivity \( \varepsilon \). The amount of infrared radiation is controlled by reducing the surface temperature of the object and the emissivity. Generally speaking, it is more difficult to control the surface temperature of an object. However, it is easier to adjust the emissivity to achieve the infrared stealth effect of the fabric.

The essence of thermal infrared imager is utilizing the difference in thermal radiation between the object and the surrounding environment. The contrast C between the target object and the surrounding environment is determined by the difference in radiation. [²]

\[ C = \frac{(E_0 - E_b)}{E_b} \]

Where the \( E_0 \) is the target radiation energy; \( E_b \) is the background radiation energy.
It can be seen from the formula that reducing the radiation energy of the target and increasing the radiation energy of the background are effective in reducing the contrast. Due to technical limitations and practical application, it is relatively feasible to reduce the radiation of the target object.

![Infrared stealth effect of different fabrics](image)

**Figure 1.** Infrared stealth effect of different fabrics

### 3 Preparation method of infrared stealth fabric

The infrared stealth fabric [3] can effectively reduce the radiation amount of the target surface, and it can be widely used in military tents, camouflage materials, military uniforms and other fields. At present, the most extensive research and application is the combination of coating materials and fabrics.

#### 3.1 Organic binder

The combination of organic adhesives and fabrics mainly include dipping and scraping, and different coating thicknesses have different absorption effects in the infrared band. The infrared transparency of the organic binder is determined by the chemical bonds, functional groups and structure. Most materials have no strong absorption in the near-infrared band, but due to the vibration of functional group molecules, they will have strong absorption in the thermal infrared region, such as C-H stretching vibration (3.3 μm), C-O stretching vibration (5.7 μm) C-H deformation vibration (7.0 μm), C-O stretching vibration (8.0 μm).

| Binder          | Polyurethane | Epoxy resin | Alkyd resin | Phenolic Resin | EPDM |
|-----------------|--------------|-------------|-------------|----------------|------|
| 8-14μm Infrared transmittance | 0.6          | 0.35        | 0.39        | 0.5            | 0.95 |

The modification of the organic adhesive can improve the adhesive by changing certain groups or molecular chains to overcome its performance defects [8]. Common modification methods include monomer copolymerization modification and graft modification.

Li et al. used EPDM as a binder and the emissivity of the coating can be reduced to 0.358 [9]. The team of Yu [10] modified the ethylene propylene rubber with low infrared emissivity which can be used...
as an organic binder. Xie et al. [11] found that the C-F bond of fluorocarbon resin has a strong attraction. Although it has certain absorption, it is suitable for infrared coating in a specific wavelength band.

3.2 Packing
Resonance will occur when the vibration frequency of the microstructure of the filler is the same as the vibration frequency of the radiation, resulting in an increase in the absorption rate.

3.2.1 Metal filler According to Kirchhoff’s law, the lower the absorption rate of the opaque body, the higher the reflectance and the emissivity. Metal fillers (Al, Cu, Ag, Sn, bronze, etc) are often opaque bodies in which atoms are closely arranged in a close-packed structure, resulting in the lower absorption and higher reflectance which is commonly needed in the field of infrared stealth. [12]

Yu [13] systematically studied the influence of the particle size and morphology of the metal filler on the infrared emissivity of the coating. When the particle size of the flake copper powder is 4 μm, the emissivity of as prepared coating can be as low as 0.10. With the increase of metal filler, the emissivity of infrared stealth fabric will decrease, but beyond a certain critical value, the infrared emissivity will increase. So far, the content of infrared stealth metal fillers reported at home and abroad does not exceed 40%, generally in the range of 20%-30%.

3.2.2 Colored filler The selection of suitable pigments is to be compatible with the needs of infrared stealth camouflage and visible light stealth, but most coloring dyes do not have low emissivity. Coloring pigments can be divided into organic and inorganic. common inorganic coloring pigments are metal oxide and hydroxide filler pigments, such as ZnO, TiO$_2$, Fe$_2$O$_3$, Ta$_2$O$_5$, Cr$_2$O$_3$, Cr(OH)$_3$; metal non-oxides: CdS, TeS, CdSe; inorganic filler salt: titanic acid salt, phosphate, acetate, chromate; common organic coloring pigments such as tetrachlorodiphenyldiazoic acid, etc.

Wang [14] compared the powder emissivity of several inorganic pigments such as Bi$_2$O$_3$, Fe(OH)$_3$, CdS, and the results showed that the infrared emissivity of the three pigments of Bi$_2$O$_3$, Sb$_2$O$_3$, and NiO was relatively low (below 0.8), which is suitable for infrared stealth coating.

3.2.3 Semiconductor filler The doped semiconductor is composed of a metal oxide (host) and a dopant (carrier donor). By changing the carrier density N, carrier mobility and carrier collision frequency. Xt, etc., the absorption and emissivity of the semiconductor can be changed by controlling the doping to make the infrared band absorption rate relatively low, the radar band absorption rate relatively higher, and forming an integrated infrared-radar material [15].

Diao Xungang [16] et al. prepared three kinds of low-emissivity nano-oxide semiconductor materials such as ITO, ZAO,TiO$_2$/Ag/TiO$_2$ nano-multilayer films by magnetron sputtering. The results show that the emissivity of ITO pigments can be The adjustment range is 0.1～0.9,and the lowest emissivity of TiO$_2$/Ag / TiO$_2$ nano multilayer film can reach 0.05.

![Figure 2. SEM of aluminum-plated fibers](image_url)
3.2.4 Combination of textiles and fillers

The combination of fillers and textiles generally use the method of adhesive bonding and the functional textiles with softness and infrared stealth effect are obtained by dipping and scraping. In addition, fillers can also be added to the process of fiber formation. There are various ways to obtain various fineness fibers and textiles with excellent physical properties and good infrared stealth effect, which expands the applicable field of fillers.

3.3 Phase change materials

Phase change materials refer to the form of latent heat, which store and release heat. The heat stored or released during the phase change is called phase change latent heat, and its temperature does not change. Due to its unique temperature control capability, the target's thermal infrared radiation intensity can be controlled by regulating the temperature of the target, while overcoming the shortcomings of low emissivity coatings. Phase change materials mainly exist in infrared stealth fabrics in the form of microcapsules.

Xu [17] linked polyethylene glycol (PEG) to cellulose laurate (LACE) to obtain the LACE/PEG graft polymer solution, and then prepared the LACE / PEG phase change energy storage fiber by electrospinning.

ZHANG et al. [18] used n-octadecane microcapsules and polyethylene particles as core materials and polypropylene as skin materials to obtain temperature-regulated fibers through melt-combination spinning;

| Tab 2. Several kinds of doped semiconductors and their properties |
|---------------------------------------------------------------|
| **Doping semiconductor** | **Infrared emissivity** |
| Antimony-doped tin oxide (ATO) | 0.35Using EPDM rubber as the binder, the coating has the lowest infrared emissivity 0.713 |
| Tin-doped indium oxide (ITO) | Using epoxy resin as adhesive, coated The infrared emissivity of the layer is 0. 568 (3~5μm), 0.599 (8~14 μm) |
| Aluminum-doped zinc oxide (ZAO) | The powder infrared emission rate is 0. 61 (8~14 μm) |
| Co-doped manganese Zinc oxide | The infrared emissivity of the sample is 0. 763 |
| Cadmium-doped zinc sulfide | The infrared emissivity of the sample is 0. 220 (3~5 μm), 0.673 (8~14 μm) |

3.4 Thermal insulation material

Hollow glass microspheres are widely used in thermal insulation coatings as thermal insulation materials because of their low density, strong compression resistance and low thermal conductivity [19]. By adding HGMs to the infrared stealth coating, the temperature of the coating surface is reduced to a certain extent. Comparing the solar reflectance and thermal insulation performance of fillers such as borosilicate hollow glass microspheres, ceramic microspheres and fly ash floating microspheres, hollow glass microspheres have a higher solar heat reflectance with a value of 0.88.
Chinese Academy of Sciences \cite{20} introduced hollow glass microspheres and pearlite sand, aerogel and other powder insulation materials and vacuum multilayer materials as well as simple high vacuum low temperature insulation performance comparison study and further explained the hollow glass microspheres research on the influence of performance change and metal coating on its low temperature insulation performance\cite{21}.

Xu Rui \cite{22} used polymeric polyaniline on hollow glass beads, then electrolessly plated silver, and finally bonded with aluminum powder-added cotton fabric through epoxy resin to obtain excellent infrared stealth, electromagnetic shielding and Fabrics with thermal radiation protection properties.

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