Hysteresis of Band Gap Position in Phase Transition-governed VO_2 Photonic Crystal

For two months I worked in the Ioffe Physico-Tecnical Institute on my 'Small Research'. Here I studied the subject 'Photonic Crystals'. The last two weeks of my stay, I worked with inverted opals or VO_2 photonic crystals, resulting in this small paper. I compared the reflection spectra of a photonic crystal with those of an inverted photonic crystal at different temperatures. The peak (or Band Gap) position of these spectra show a clear hysteres loop. In this paper I will present the experimental results of my experiments during these last two weeks.

In my experiments I worked with silica-opal-VO_2 composites and their inverse equivalent VO_2 photonic crystals. To study their photonic band gap (PBG) properties and in particular the hysteresis loop due to the phase transition in VO_2, I measured the reflection spectra from the (111) lattice planes. Sample K-162-1 was studied only for detailed measurements of the hysteresis loop. Sample K-168-2 was studied carefully before and after inversion.

Figure 1 shows the thermal hysteresis loop PBG of K-162-1. The heating branch begins at about 65 ^{0}C, coinciding with that for single VO_2 crystal. At low temperatures the PBG of the cooling branch does not coincide with the heating branch. The most probable reason for this is that the sample changes position and angle during the heating process. For this reason it is not sure whether the steps in the hysteresis loop are due to this effect or that they coincide with the steps in the thermal hysteresis loop of the opal-VO_2 composite conductivity[1].

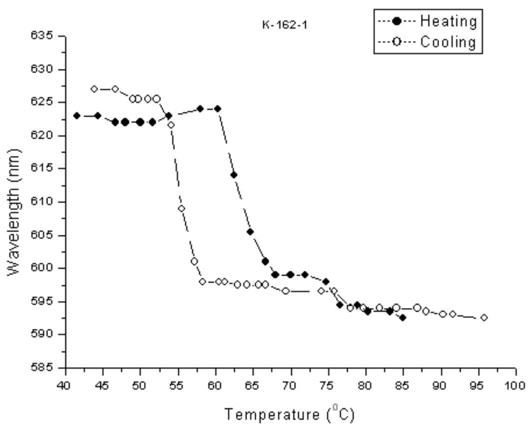

fig. 1 Thermal hysteresis loop of the reflection peak position of the opal - VO_2 composite K-162-1

The next step was improving my set up, in order to obtain good spectra and a correct hysteresis loop. Figure 2(a) shows reflection spectra before and after the phase transition and (b) again the thermal hysteresis loop of sample K-168-2. The shift of the PBG is about 36 nm, just like K-162-1. Also, the intensity decreases when the VO_2 is in the metallic phase (T = 348 K), in agreement with theoretical estimations. The steps in the hysteresis loop have almost disappeared, but there are also fewer points then in fig. 1.

(a)

(b)

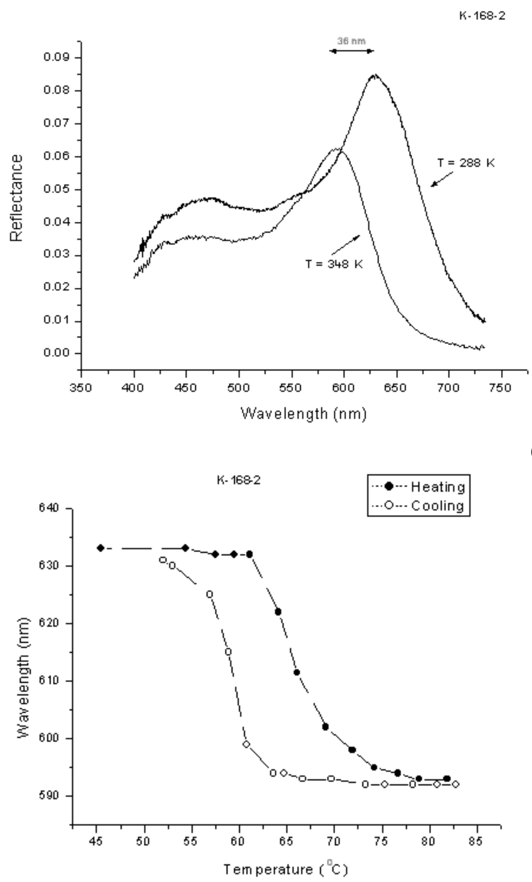

fig. 2 (a) Reflection spectra from (111) plane of K-168-2 before and after phase transition and (b) the thermal hysteresis loop of PBG of opal K-168-2

First results of reflectance spectra of inverse opal were promising, but it had to take another week before I could obtain satisfying results. These results are shown in figures 3(a) and (b). The results are promising but they still are very global results. The shift in PBG is about 38 nm, which is comparable to the absolute shift of PBG before inversion. Again, intensity decreases when the VO_2 is in the metallic phase. The spectra have also become wider then before inversion. The hysteresis loop does not show steps anymore. This is may be due to the fact that there are not many measurements in the important region 55-70°C. On purpose of clarity I did not take errors in account in the different graphs. The error in the position of the PBG is about 2 nm. The error in temperature is about 3 ^{0}C.

(a)

(b)

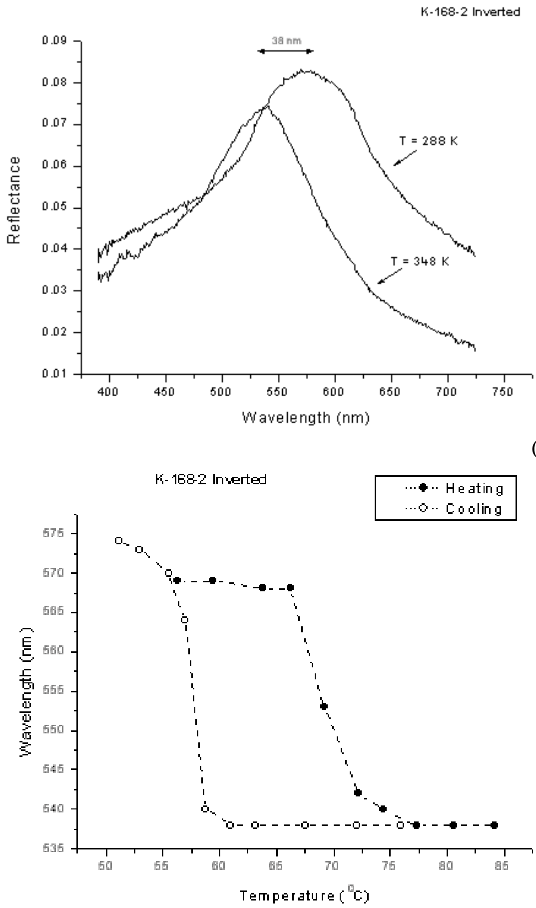

fig 3(a) Reflection spectra from (111) plane of the inverted opal K-168-2 before and after phase transition and (b) the thermal hysteresis loop of PBG of the inverted opal K-168-2.

In order to improve these results the measurements must take shorter time. Every point in the hysteresis loop takes about 3 minutes and that is much to slow to observe possible stepwise behavior of this hysteresis loop. Also, the set up for measuring the temperature has to be improved, because during the experiment only the temperature in the vicinity of the sample was known and not the actual temperature of the sample.

Well, this gives rise to new experiments, but better results require better equipment, but also a better physicist. These experiments can not be done by a fourth year physics student, who does not understand the Russian language in which his professor is talking, although, this was one of the reasons for going to Russia. Not only work in a very renown Institute and get experience in experimental physics, but also to get acquainted with another foreign language and culture. My colleagues in this Institute helped me with this enormously. Therefor I want to thank Sasha Pevtsov for letting me work in his group. I have to thank Sasha Iliinsky for teaching me and assisting at the measurements. And I am grateful to Dima Kurdyukov for letting me work with his precious samples. Gazi Aliev gave me a very proper introduction to this subject and therefor I am also grateful to him. Most of all I have to thank Andrey Akimov, who arranged everything concerning my exchange to Russia.

[1]V. G. Golubev et al., Appl. Phys. Lett.,**79**, 13 (2001)