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Synthesis, characterization and microwave properties of strontium hexaferrite thin films prepared by chemical bath deposition

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ABSTRACT

Strontium hexaferrite thin films were deposited on alumina by chemical bath deposition technique. The thin films formed with different synthesis pH were annealed by microwave heating. The effect of variation of pH of the solution during synthesis on the structural, morphological and microwave properties was studied by X-ray diffraction, scanning electron microscopy, waveguide reflectometer and slotted section technique. The strontium hexaferrite thin films synthesized at pH 10 show highly dense surface morphology and hence, high microwave transmittance of ~65% in the 8–12 GHz frequencies. With further increase in transmittance by tailoring the permittivity and permeability, these strontium hexaferrite thin films can be used as microwave transmitting material.

1. Introduction

Strontium hexaferrite has been conventionally used as permanent magnet however, in recent years the development of radar electronics and wireless technologies has led to the requirement of planar and low loss magnetic microwave devices. Strontium hexaferrite has attracted much attention for microwave device applications because of its properties of high permeability, large magnetocrystalline anisotropy, excellent chemical stability [1] and low conductive losses.

The techniques used for the deposition of hexaferrite thin films are sputtering [2], pulsed laser deposition [3,4], metalorganic chemical vapor deposition [5], sol–gel [6], molecular beam epitaxy [7], spin coating-sol gel [8,9]. A long sought goal of the ferrite community has been the integration of ferrite-based microwave passive devices with semi-conductor electronics. This requires the growth of ferrites on semiconductor substrates. Oriented hexaferrite films to be deposited on semiconductor substrates have the requirement of temperatures to grow a ferrite having low microwave loss.

In this paper, the strontium hexaferrite (SrM) thin films prepared on alumina substrate by chemical bath deposition technique followed by annealing using microwave heating is reported. The structural and microwave properties of the deposited SrM thin films are reported. In the present work, the effects of the pH of the starting solution on the structural and microwave properties of strontium hexaferrite thin films were investigated.

2. Experimental details

The strontium hexaferrite thin films were deposited by chemical bath deposition technique. The starting materials such as $SrCl_2{\cdot}6H_2O$, $FeCl_3{\cdot}6H_2O$ along with NaOH, Na_2CO_3 and polyvinyl alcohol (PVA) were used. The 0.1 N PVA solution (solution-I) was prepared in distilled water. The NaOH and Na_2CO_3 base solution was prepared with weight ratio 3:1 and dissolved in water to make 1 N base solution (solution-II). The solution-II was then added into solution-1 dropwise along with heating and stirring. This solution mixture was used to obtain colloidal solution of chlorides with desired pH. The $FeCl_3{\cdot}6H_2O$ and $SrCl_2{\cdot}6H_2O$ were weighed stoichiometrically for molar ratio 12:1. The weighed chlorides were dissolved in distilled water forming 1 N solution. After they dissolved completely, the solution made up of mixture of solution-I and solution-II, was added drop wise into solution of chlorides. The colloidal solution was obtained for pH 9, 10, 11 and 12. The alumina (Al_2O_3) substrates were used for deposition. The $SrCl_2/FeCl_3$/PVA/NaOH/Na_2CO_3 solution was stirred continuously during deposition. The deposition time was 5 h. These films were then annealed at 900 W for 40 min in the microwave oven. The crystal structure determination using by CrKα radiations using Philips diffractometer (PW 3710), surface morphology studies by JSM-JEOL 6360 and microwave transmittance, reflectance, complex permittivity and permeability of the deposited strontium hexaferrite thin

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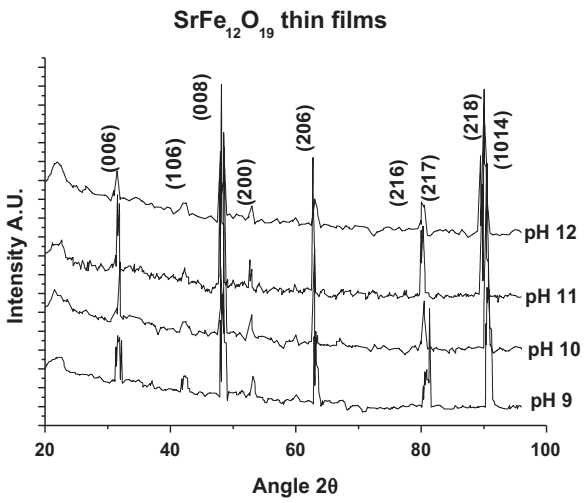

Fig. 1. X-ray diffraction pattern of strontium hexaferrite thin films.

films by waveguide reflectometer and voltage standing wave ratio (VSWR) technique is reported in this article.

3. Results and discussions

3.1. Film structure and morphology

The crystal structure of the strontium hexaferrite thin films was determined by X-ray diffraction technique. The X-ray diffraction pattern of the SrM thin films synthesized under pH 9, 10, 11 and 12 is shown in Fig. 1. The hexagonal crystal system of dominant (2 1 8) plane with *P*63/mmc space group was obtained. Quantitative information concerning the preferential crystallite orientation is obtained from texture coefficient. TCs (*hkl*) defined by relation [10],

$$TC(hkl) = \frac{I(hkl)/I_0(hkl)}{1/\left(N\sum_N (I(hkl)/I_0(hkl))\right)}$$

where $I(hkl)$ is the measured intensity, $I_0(hkl)$ is the ASTM intensity and N is the reflection number. The calculated texture coefficient (TC) of each significant plane (hkl) is tabulated in Table 1. The orientation of planes at (1 0 1 4) is more in all the samples, this reorientation effects might be due to microwave annealing. Table 2 shows that the crystallite size of the films increased with increase in the pH of the solution due to easier formation of SrM phase at the higher pH values from pH 9 to pH 11. It can also be observed from Table 2 that the values of lattice parameters are different from those of the single and strain-free crystals of SrM powder (a = 5.886 Å, c = 23.037 Å, according to JCPDS Card No. 33-1340). This can be attributed to the thermal stresses, induced during calcinations process, originated from the difference between the thermal expansion coefficients of the SrM film and the alumina substrate.

The crystallite size calculated by Debye Scherer's method [11], cell volume and X-ray density of these SrM thin films is tabulated in Table 2. The SrM thin films obtained due to pH 10 show lowest cell volume and highest density whereas, the largest crystals were formed for SrM thin films due to pH 11. Shift of XRD peaks to lower angle due to increase in lattice parameter '*a*' which is also responsible for increase in crystallite size for SrM thin films when synthesized with pH 9–11 and decreased due to synthesis at pH 12. The crystallite size of the films increased with increasing the pH of the solution due to easier formation of SrM phase at the higher pH values.

The surface morphologies of the films with pH 9, 10, 11 and 12 are shown in Fig. 2, respectively. It was observed that, the interconnected grains with porous fibril like surface morphology was

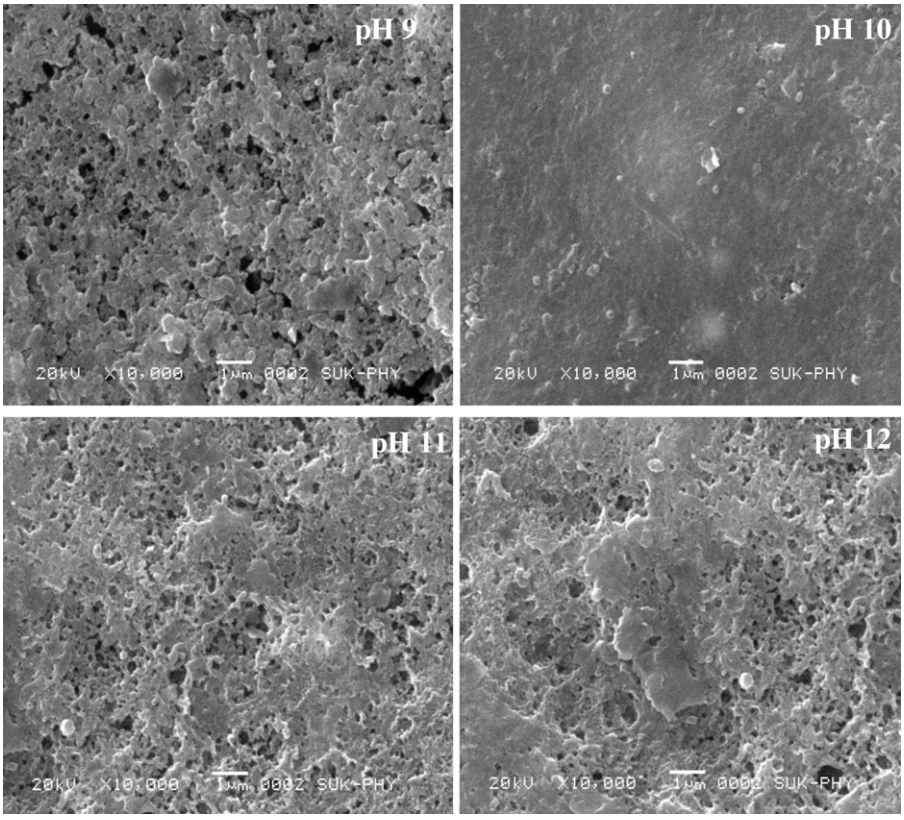

Fig. 2. SEM images of strontium hexaferrite thin films.