Microwave magnetoabsorption in $R_{0.6}Sr_{0.4}MnO_3$ ($R = Pr$ and $Nd$)

A Chanda, U Chaudhuri and R Mahendiran

Physics Department, 2 Science Drive 3, National University of Singapore, Singapore 117551, Singapore

E-mail: phyrm@nus.edu.sg

Received 15 October 2019, revised 8 February 2020
Accepted for publication 21 February 2020
Published 24 March 2020

Abstract
We report microwave (MW) magnetoabsorption ($\Delta P$) at room temperature in $R_{0.6}Sr_{0.4}MnO_3$ ($R = Pr$ and $Nd$) samples. $\Delta P$ as a function of dc magnetic field ($-2.5 \text{kOe} \leq H_{dc} \leq 2.5 \text{kOe}$) was measured for a broad frequency range ($f = 0.1$–4 GHz) of an MW magnetic field using a vector network analyzer and a copper strip coil which encloses one of the above samples. As the external dc magnetic field decreased from the maximum value, $\Delta P$ initially increases and shows a maximum for a critical field and then decreases as the field approaches zero. The critical field value increases with increasing frequency of the MW signal. Line shape analysis of the obtained spectra suggests that the observed features in $\Delta P$ are caused by ferromagnetic resonance in $R = Pr$ and electron paramagnetic resonance in $R = Nd$ samples, which were later confirmed using a coplanar waveguide-based broadband magnetic resonance spectrometer.

Keywords: manganites, microwave magnetoresistance, ferromagnetic resonance, electron spin resonance, network analyzer

(Some figures may appear in colour only in the online journal)

1. Introduction
Doped manganites of the formula $R_{1-x}A_{x}MnO_3$ where $R = La^{3+}, Pr^{3+}, Nd^{3+}$, etc, and $A = Sr^{2+}, Ca^{2+}$, etc, are well known for the colossal magnetoresistance effect—a dramatic decrease of electrical resistance under external magnetic fields exhibited by them [1]. An interesting and yet relatively less explored property of these oxides is the magnetic field dependence of microwave absorption (MWA). Available reports indicate that microwave (MW) absorption in some members of this oxide family is more sensitive than dc electrical resistance to external magnetic fields, particularly in the vicinity of paramagnetic to ferromagnetic transition. For example, Owens [2] found a 50% change in MW surface resistance in polycrystalline $La_{0.7}Sr_{0.3}MnO_3$ in a small magnetic field of $H = 600 \text{ Oe}$ and Srinivasu et al [3] reported a still higher change (~80%) for the same field strength in $La_{0.7}Ba_{0.3}MnO_3$ powder, but Tyagi et al [4] found smaller magnetoabsorption (~20% for $H = 10 \text{ kOe}$) in $La_{0.7}Ba_{0.3}MnO_3$ thin film. A maximum MWA occurs when the resonance frequency of the impinging MW magnetic field coincides with the precessional frequency of the magnetization. MWA can also occur near the zero-field due to the domain magnetization process or magnetoabsorption in a ferromagnetic sample which causes low-field non-resonant MWA [5, 6]. Magnetoabsorption was also used to detect a magnetization avalanche in a phase-separated $La_{0.225}Pr_{0.4}Ca_{0.375}MnO_3$ [7]. In the majority of the available reports, a commercial electron spin resonance (ESR) spectrometer was used to record the MWA spectra while sweeping an external dc magnetic field at a single frequency (~9.8 GHz) dictated by the natural resonance frequency of the resonant cavity [8–11]. There are a few reports of frequency-swept MWA in zero external magnetic field in $La_{1-x}Sr_{x}MnO_3$ ($x = 0.2–0.33$) samples using a vector network analyzer (VNA) and specially designed transmission line [12] or shorted coaxial cables [13–17]. However, broadband MWA in the presence of a magnetic field was not studied in those works. Also, there is no previous report on the broadband MWA in the paramagnetic state of manganites.

Here, we report microwave magnetoabsorption (MWMA) in ferromagnetic ($R = Pr$) and paramagnetic ($R = Nd$) samples with the composition $R_{0.6}Sr_{0.4}MnO_3$ over a broad frequency range (0.1–4 GHz) by making use of a VNA and a copper strip coil. The strip coil serves as a trans-receiver to radiate the MW field and sense the high-frequency magnetic response.
Figure 1. A schematic representation of the strip coil-based MW power absorption setup.

of the material. Novelties of the present work include: (1) our broadband ferromagnetic resonance (FMR)/ESR technique makes use of a copper strip coil instead of a microfabricated coplanar-waveguide (CPW) or microstrip; (2) we observe a frequency tunable peak in the field dependence of MW A, which we attribute to FMR in the Pr-based manganite and ESR in the Nd-based manganite; (3) our interpretations are supported by the detection of FMR and ESR signals using a CPW-based commercial spectrometer which makes use of the lock-in technique and measures the MW A as a field derivative (dP/dH).

2. Experimental details

Polycrystalline samples of $R_{0.6}\text{Sr}_{0.4}\text{MnO}_3$ ($R = \text{La, Pr and Nd}$) were prepared by the conventional solid-state reaction method. Magnetization of these samples was measured using a vibrating sample magnetometer incorporated into a physical property measurement system (PPMS). For the MWMA measurement, these samples were cut into rectangular geometry with dimensions of 3 mm length $\times$ 3 mm width $\times$ 2 mm thickness. A cuboidal shaped strip coil of similar dimensions was made from a copper sheet of 0.2 mm thickness. A schematic illustration of our experimental setup is shown in figure 1. The sample was firmly fitted into the strip coil and the inner surface of the coil was also covered with a thin layer of Kapton tape to insulate the copper coil and prevent it from touching the sample. The two ends of the coil were connected to a VNA (Agilent model N5230A) using a sub-miniature A-type (SMA) connector and radio frequency (RF) cables. The VNA sources the MW power to the load (copper strip) and measures the reflected power to the same port. The output power of the VNA was maintained at a constant power (10 dBm). A maximum power will be delivered to the strip coil if its impedance is matched to 50 $\Omega$ [18, 19]. However, our copper strip coil is not impedance-matched. Impedance matching is not essential in our case as we are interested in the relative change of MW A without and with an external $dc$ magnetic field. An electromagnet was used to sweep the $dc$ magnetic field ($H_{dc}$). The magnetic field dependence of MW power absorption was measured in terms of the $S_{11}$ scattering parameter of the electromagnetic wave reflected from the load upon change in MW property of the sample while sweeping the $dc$ magnetic field. The VNA measures the magnitude of the $S_{11}$ parameter in terms of decibels (dB). The SMA connector which links the strip coil and the RF cable has traces of magnetic impurities which gives a non-negligible contribution to the $\Delta P$ spectra for the paramagnetic sample. To eliminate the contribution from the SMA connector, data were also taken with the empty coil for each frequency and subtracted from the data measured with the sample inside the coil.

The field derivative of MW power absorption (dP/dH) as a function of the magnetic field at room temperature was measured using a commercial broadband ferromagnetic resonance spectrometer (NanOsc Cryo FMR$^\text{TM}$, Quantum Design Inc., USA) integrated to the PPMS.
Figure 2. Temperature dependence of magnetization (M) of the samples R = Pr and Nd in R0.6Sr0.4MnO3 series in a magnetic field of $H_{dc} = 1$ kOe. The ferromagnetic Curie temperature ($T_C$) determined from the minimum of $dM/dT$ curves is $T_C = 305$ and 273 K for the samples R = Pr and Nd, respectively. Thus, the sample R = Pr is ferromagnetic at room temperature whereas R = Nd is a room temperature paramagnet. The magnetic field dependence of magnetization (M) at room temperature is shown in the inset for both the samples. $M(H)$ of R = Pr shows typical behavior of a soft ferromagnet: a rapid increase in low magnetic fields followed by saturation at higher fields. On the other hand, M increases linearly with $H$ for the R = Nd sample which confirms paramagnetism in this sample at room temperature.

We compare the dc magnetic field ($H_{dc}$) dependence of the change in MW power absorption ($\Delta P$) at room temperature for samples R = Pr and Nd in the figures 3(a) and (b), respectively, for three representative frequencies of MW magnetic field ($f = 0.1$, $1$, and $4$ GHz). The $P$ value at the highest field is taken as the reference. For R = Pr and $f = 0.1$ GHz, the $\Delta P$ versus $H_{dc}$ curve exhibits a single peak at the origin $H_{dc} = 0$. It implies that the MW power absorption decreases as the magnetic field is increased from zero field. When $f = 1$ GHz, $\Delta P$ shows broad peaks around $H_{dc} = H_p = 178$ Oe on either sides of the origin and a dip at $H_{dc} = 0$. At $f = 4$ GHz, the magnitude of the peak is enhanced and $H_p$ is shifted to a higher magnetic field ($H_p = 772$ Oe). The $\Delta P$ versus $H_{dc}$ for R = Nd does not show a peak at the origin for $f = 0.1$ GHz and the signal is weak compared to the ferromagnetic sample. A double-peak structure is visible at $H_{dc} = 1$ Hz for $f = 1$ GHz and 4 GHz and the peak position shifts to higher magnetic fields as the frequency increases. However, $\Delta P$ is nearly field-independent between $+H_L$ and $-H_L$ for the Nd sample in contrast to the Pr sample for which $\Delta P$ smoothly increases as the dc field is increased from 0 Oe to $H_p$ or $-H_p$. It should be pointed out that $H_L > H_p$ for a fixed frequency. For $f = 4$ GHz, $H_L = 1.8H_p$. Also, the shift in the peak position ($\Delta H_{dc} = 925$ Oe) for the Nd sample is higher than that of the Pr sample ($\Delta H_{dc} = 594$ Oe) for $\Delta f = 3$ GHz. Thus, the anomalous features observed in MWMA are distinct in the Pr and Nd samples.

We have plotted the three-dimensional graph of $\Delta P$ as a function of the frequency of the electromagnetic field ($f = 0.1$–$4$ GHz) and dc magnetic field ($H_{dc}$) for R = Pr and Nd in figures 3(c) and (d), respectively. It is obvious that the broad peaks at $H_{dc} = \pm H_p$ for the Pr sample and sharp peaks at $H_{dc} = \pm H_c$ for the Nd sample move apart from each other towards higher $H_{dc}$ values with increasing frequency of the MW electromagnetic field. The peaks at $H_{dc} = \pm H_c$ for the R = Nd sample are much sharper and positioned at higher field values in contrast to broad peaks at $H_{dc} = \pm H_p$ for the R = Pr sample.

4. Discussion

We would like to know the origin of the observed anomalies in the MWMA in the samples studied here. It is known that ferromagnetism in manganites originates from the double exchange interaction between Mn$^{3+}$(t$_{2g}^{-1}e_g^{-1}$) and Mn$^{4+}$(t$_{2g}^{-3}e_g^{0}$) ions. Both localized t$_{2g}^{-3}$ core spins and itinerant, e.g. electron spin of Mn ions, collectively contribute to the overall magnetization of the sample. In our measurement configuration, the propagation of MW in the strip coil creates a MW magnetic field ($H_{MW}$) along the axis of the coil and hence through the length of the sample. The MW magnetic field $H_{MW}$ and the applied dc magnetic field $H_{dc}$ are orthogonal to each other as in the field configuration in a conventional ESR spectrometer. Hence, the magnetization undergoes a precessional motion around the effective magnetic field ($H_{eff}$) which is a combination of the anisotropy field ($H_K$) and $H_{dc}$. A resonant absorption occurs when the frequency of the MW magnetic field matches with the frequency of magnetization precision. This phenomenon is known as ESR in the case of a paramagnetic sample and FMR in the case of a ferromagnetic sample. Since the Nd sample is paramagnetic at room temperature, the sharp peak absorbed in MWMA is caused by ESR. A collective precession of the exchange-coupled Mn$^{3+}$ ($S = 3/2$) ions via the Mn$^{3+}$ ($S = 2$) spin system gives rise to ESR in paramagnetic manganites [20]. In an external dc magnetic field, degenerate t$_{2g}$ and, for example, levels of the Mn ions Zeeman split into spin-up and spin-down energy levels. If the sample is subjected to an MW magnetic field in the transverse direction to $H_{dc}$, resonance occurs when the energy gap between the Zeeman-split spin-up and spin-down levels matches with the energy of the MW magnetic field. Under the resonance condition, the paramagnetic sample absorbs maximum power from the MW field and the t$_{2g}^{-3}$ spin undergoes a spin–flip transition from lower to higher energy levels. The magnetic field ($H_{dc}$) dependence of the out-of-phase component of permeability ($\mu''$) will be maximum at $H_{dc} = H_{res}$ where $H_{res}$ is the resonance field. The power absorbed ($P$) by a sample is related to $\mu''$ through the relation $P = \frac{1}{2}V\mu''\omega H_{MW}^2$, where $H_{MW}$ is the amplitude of
the MW magnetic field and \( V \) is the sample volume through which the MW field penetrates \([21]\). Hence, while sweeping the external magnetic field, \( P(H) \) goes through a peak value at \( H_{\text{res}} \). Thus, the observed features in MWMA can be ascribed to FMR for \( R = \text{Pr} \) and EPR for \( R = \text{Nd} \) samples. The single peak feature in the \( \Delta P \) versus \( H \) curves at \( H_{dc} = 0 \) for frequencies below 0.5 GHz for the ferromagnetic sample \( R = \text{Pr} \) is a non-resonant absorption feature caused by magnetoresistance and domain rotation processes \([5, 6]\).

The magnetic field dependence of MW power absorption, \( P(H_{dc}) \), usually follows the Lorentzian function described by \([22]\):

\[
P(H_{dc}) = P_{\text{max}} \frac{(\Delta H^2)}{(H_{dc} - H_{\text{res}})^2 + (\Delta H^2)} \tag{1}
\]

where \( P_{\text{max}} \) is the maximum power absorption at \( H_{dc} = H_{\text{res}} \) and \( \Delta H \) is the line width (full line width at half maximum). However, in a conducting ferromagnet, penetration of the MW magnetic field is limited to the skin depth \( (\delta) \) which is controlled by the frequency dependence of the permeability \( (\mu) \) of the sample through the relation: \( \delta = \sqrt{\frac{2\pi}{\mu f \rho}} \) where \( \rho \) is the dc resistivity. In the limit of strong skin effect, the power absorption is proportional to \( \sqrt{\mu} + \mu'' \) where \( \mu = \mu' - i\mu'' \) and the dispersive \( (\mu'') \) component mixes with the absorption component \( (\mu') \) \([21]\). While the absorptive component is described by a symmetric Lorentzian function (as shown in equation (1)), the dispersive component follows an antisymmetric Lorentzian function. Hence, the resultant power absorption spectrum for a metallic ferromagnet can be described by a linear combination of symmetric and antisymmetric Lorentzian functions as \([23]\):

\[
P(H_{dc}) = P_{\text{sym}} \frac{(\Delta H^2)}{(H_{dc} - H_{\text{res}})^2} + P_{\text{asym}} \frac{(\Delta H^2)}{(H_{dc} - H_{\text{res}})^2} + P_0 \tag{2}
\]

where \( P_{\text{sym}} \) and \( P_{\text{asym}} \) are the coefficients of symmetric and antisymmetric Lorentzian functions, respectively, and \( P_0 \) is a constant offset parameter. Although equations (1) and (2) are valid for narrow resonance line shapes they have been used to estimate the line widths qualitatively.

At \( T = 300 \) K, dc resistivity \( \rho = 54.7 \) m\(\Omega\) cm and 76.9 m\(\Omega\) cm for \( R = \text{Pr} \) and Nd samples, respectively. The non-magnetic (\( \mu = 1 \)) skin depth \( (\delta) \) for the \( R = \text{Pr} \) and Nd samples are \( \delta = 186 \) and 221 \( \mu \)m, respectively, for \( f = 4 \) GHz, which are larger than the average grain size (~3 \( \mu \)m) of the samples but smaller than the sample dimensions (2 mm thick, 3 mm in width). Hence, the influence of eddy current needs to be considered while analyzing the resonance line shapes. Recently, Plovik et al \([24, 25]\) showed that the dispersive line shape arising from the out-of-phase driving fields induced by eddy...
dependence of the line width for the sample R

\[ \text{Figure 4. (a) Lorentzian fit of the } \Delta P \text{ line shapes for the sample } R = \text{Pr at selected frequencies between } f = 2-4 \text{ GHz. (b) Main panel shows } f-H_{\text{res}} \text{ curve obtained from the } \Delta P \text{ line shape analysis for the sample } R = \text{Pr with the Kittel fit and inset shows } f \text{ dependence of the line width } \Delta H. \]


currents can also be described by an antisymmetric Lorentzian function. Thus, the second term in equation (2) accounts for the contributions from both the dispersive component of permeability as well as the eddy current effects.

Generally, the magnetic field dependence of MW power absorption \( P(H_{dc}) \) for a conducting paramagnetic sample is described by the Dysonian form as [26, 27]:

\[ P(H_{dc}) = I_0 \Delta H + \beta (H_{dc} - H_{\text{res}}) \]

\[ = \frac{\Delta H + \beta (H_{dc} - H_{\text{res}})}{4(H_{dc} - H_{\text{res}})^2 + (\Delta H)^2} \]

\[ (3) \]

where \( I_0 \) is the signal intensity and \( \beta (0 \leq \beta \leq 1) \) is the asymmetry parameter. \( \beta \) is the ratio of the dispersive component to the absorptive component of the resultant signal. Equation (3) is valid for a narrow resonance line (\( \Delta H \ll H_{\text{res}} \)). On the other hand, the field dependence of the resultant MW power absorption for broad resonance line shapes (\( \Delta H \gg H_{\text{res}} \)) is described by the following expression [27]:

\[ P(H_{dc}) = I_0 \left[ \frac{\Delta H + \beta (H_{dc} - H_{\text{res}})}{4(H_{dc} - H_{\text{res}})^2 + (\Delta H)^2} \right. \]

\[ + \left. \frac{\Delta H + \beta (H_{dc} + H_{\text{res}})}{4(H_{dc} + H_{\text{res}})^2 + (\Delta H)^2} \right]. \]

\[ (4) \]

Since for the \( R = \text{Nd sample}, \Delta H \ll H_{\text{res}} (H_{\text{res}} \sim 1.35 \text{ kOe and } \Delta H < 0.5 \text{ kOe at } f = 4 \text{ GHz}), \) the line shapes can be described by equation (3). Multiplying both the numerator and the denominator of the equation (3) by \( \Delta H \), we get,

\[ P(H_{dc}) = \frac{I_0 \Delta H}{4(H_{dc} - H_{\text{res}})^2 + (\Delta H)^2} \]

\[ \times \frac{\Delta H + \beta (H_{dc} - H_{\text{res}})}{\left(\Delta H + \beta (H_{dc} - H_{\text{res}})\right) + \left(\Delta H + \beta (H_{dc} + H_{\text{res}})\right)} \]

\[ (5) \]

Thus, the expression of \( P(H_{dc}) \) described by equation (5) is identical to equation (2) with \( P_{\text{sym}} = \frac{I_0}{\Delta H} \) and \( P_{\text{asy}} = \frac{\beta I_0}{2\Delta H} \). Hence, the \( \Delta P(H_{dc}) \) line shapes for both ferromagnetic and paramagnetic resonances can be described by equation (2). We fitted the \( \Delta P(H_{dc}) \) line shape at frequencies higher than 2 GHz using equation (2) for both the samples. Figure 4(a) shows the fit of the \( \Delta P \) versus \( H_{dc} \) line shapes using the above equation at selected frequencies for the ferromagnetic sample \( R = \text{Pr}. \) The main panel of figure 4(b) shows the plot of frequency \( f \) versus \( H_{\text{res}} \) for the \( R = \text{Pr} \) sample. The f versus \( H_{\text{res}} \) curve for this sample follows Kittel’s equation for ferromagnetic resonance [28],

\[ f = \frac{1}{2\pi} \left\{ \gamma H_{dc} + (N_z - N_z^*) \omega_0 \right\} \]

\[ \times \left\{ \gamma H_{dc} + (N_z - N_z^*) \omega_0 \right\}^{1/2} \]

\[ (6) \]
where $\omega_0 = 4\pi\gamma M_S$, $N_e$, $N_i$, and $N_f$ are the demagnetization factors for the sample geometry, and $N_{e,a}$ and $N_{i,a}$ are the demagnetization factors due to magnetocrystalline anisotropy and $M_S$ is the saturation magnetization. $\gamma$ is the gyromagnetic ratio given by $\gamma = g\mu_B/h$, where $g$ is the Landé $g$-factor. The demagnetization factors can be determined assuming ellipsoidal geometry of the sample [29]. For our sample dimensions, the values of $N_e$, $N_i$, and $N_f$ are 0.272, 0.272 and 0.456, respectively. For simplification, we assume in-plane anisotropy with $N_{e,a} = N_{i,a} = H_K/M_S$, where $H_K$ is the anisotropy field. The value of $\gamma/2\pi$ for the Pr sample extracted from the Kittel fit described by equation (6) is 2.78 MHz Oe$^{-1}$, which is close to the free electron value ($\gamma/2\pi = 2.8$ MHz/Oe). We also obtained $4\pi M_S = 1552 \pm 100$ Oe and $H_K = 195 \pm 10$ Oe, respectively. The value of $H_K$ obtained from the magnetoabsorption data for the sample $R = $ Pr closely matches with $H_K = 206 \pm 15$ Oe, estimated by fitting the $M(H)$ isotherm of this sample (see inset of figure 2(b)) with the law of approach to saturation (LAS) model which is usually expressed as [30]:

$$M = M_s \left(1 - \frac{a}{H} - \frac{b}{H^2}\right) + \chi H$$

(7)

where the coefficients $a$ and $b$ are connected to micro-stress and the first-order magnetocrystalline anisotropy coefficient ($K$), respectively. The anisotropy field $H_K$ can be calculated using the relation $H_K = 2 K M_s^{-1}$. The value of $M_S$ obtained from the LAS fit is 28 emu g$^{-1}$. Using the value of mass density (estimated by the Archimedes principle), $\rho_m = 3.25$ g cm$^{-3}$, the calculated value of $4\pi M_S$ for the $R = $ Pr sample is 1143.5 Oe, which is slightly lower than the value of $4\pi M_S = 1552 \pm 100$ Oe obtained from the Kittel fit. The discrepancy between these two $M_S$ values could arise from the fact that the measurement is done at 300 K, which is closer to the ferromagnetic Curie temperature ($T_C = 305$ K) and the magnetization is not saturated in a field of 2.5 kOe at room temperature. The inset of figure 4(b) shows the variation of the line width $\Delta H$ with frequency and it shows a non-linear frequency dependence in the measured frequency range. The ferromagnetic Curie temperature of the Pr sample ($T_C = 305$ K) is not far from the temperature of the measurement. Other than the intrinsic Gilbert damping mechanism, extrinsic contributions such as magnetic inhomogeneity within grains, porosity, two-magnon scattering and eddy current in the sample could lead to broadening of the line width [31, 32]. Since our samples are polycrystalline, it is highly probable that the extrinsic effects dominate and lead to a non-linear scaling of the line width with frequency. Measurements as a function of temperature are needed to understand the exact mechanism of line broadening.

Figure 5(a) shows the fitting of $\Delta P$ ($H_{dc}$) line shapes at selected frequencies for the paramagnetic sample $R = $ Nd using equation (2). The frequency dependence of $\Delta H$ extracted from the fitting is shown in the inset of figure 5(b) which also shows a non-linear frequency dependence. The values of $\Delta H$ for this sample are clearly much smaller than the ferromagnetic sample $R = $ Pr. The main panel of figure 5(b) clearly indicates that $H_{res}$ increases linearly with $f$ and thus follows the condition for ESR, i.e. $f = (\gamma/2\pi) H_{agr}$. A linear fit to the $f$ versus $H_{res}$ curve yields $\gamma/2\pi = 2.87$ MHz Oe$^{-1}$ which is close to the free electron value.

In order to confirm our observations of FMR and ESR in the samples $R = $ Pr and Nd, magnetic resonance measurements were also performed on both these samples using a commercial broadband FMR spectrometer. This measurement makes use of a CPW-based technique and records the field derivative of the MW power absorption ($dP/dH$) at $f = 4$ GHz (left y-scale) measured using broadband FMR spectrometer and corresponding change in power absorption ($\Delta P$) estimated by integrating the $dP/dH$ data over the measured field range (right y-scale) for the samples (a) $R = $ Pr and (b) $R = $ Nd.

Numerical integration was performed on the $dP/dH$ spectra to estimate the corresponding change in MW power absorption ($\Delta P$) as a function of $H_{dc}$ (see right y-scales of figures 6(a) and (b)). It is clear that the line shapes of the $\Delta P$ line obtained from the Cryo-FMR technique for both the samples are similar to that obtained from the strip coil VNA technique at the same frequency. Furthermore, the positions of the resonance fields ($H_{res}$) at $f = 4$ GHz obtained from both techniques closely match with each other for both $R = $ Pr and Nd samples, which validates the observations of FMR and ESR in these samples using our broadband detection method.

5. Summary

In summary, we have investigated MWA of ferromagnetic ($R = $ Pr) and paramagnetic ($R = $ Nd) samples in $R_{0.6}$Sr$_{0.4}$MnO$_3$ series as a function of the $dc$ magnetic field.
over a broad frequency range (0.1–4 GHz) using a VNA and a copper strip coil at room temperature. Our MW magnetoabsorption results show features of FMR for the sample \( R = \text{Pr} \) and ESR for the sample \( R = \text{Nd} \), which were further confirmed by a CPW-based broadband FMR spectrometer. By performing the line shape analysis, we have extracted the gyromagnetic ratio, saturation magnetization and anisotropy field for the ferromagnetic sample.

Acknowledgments

R M thanks the Ministry of Education for supporting this work (Grant Nos. R144-000-373-112 and R144-000-381-112).

ORCID iDs

A Chanda https://orcid.org/0000-0001-9681-0312
R Mahendiran https://orcid.org/0000-0003-2335-3442

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